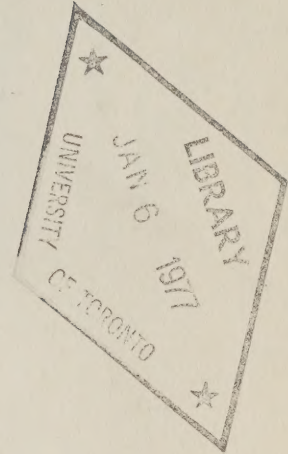


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WASTE OIL RECYCLING STUDY



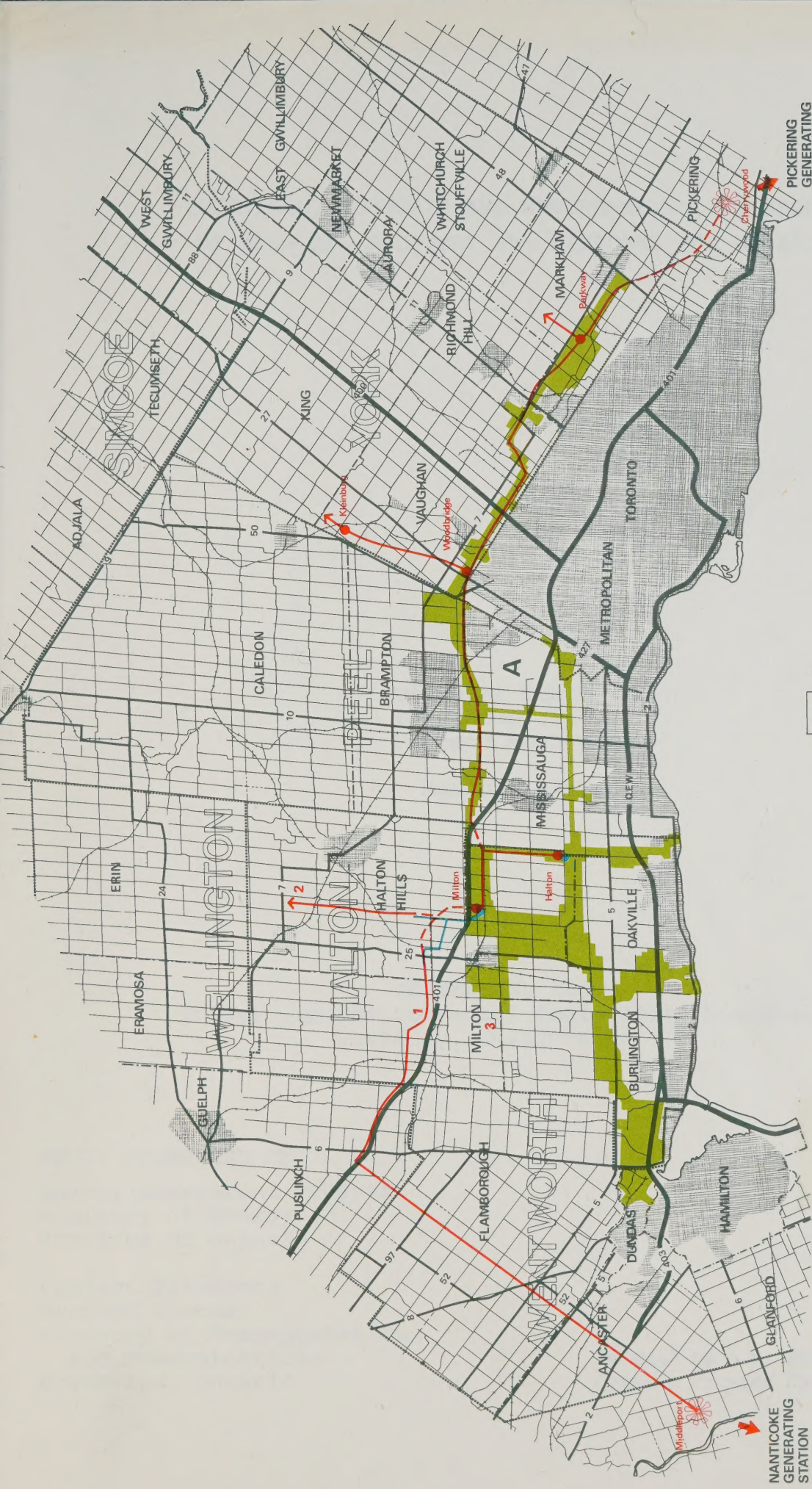
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Ontario

A Report Prepared for The Ontario Energy Management
Program by TEKNEKRON, Inc., Berkeley, California



Niagara Escarpment Crossings

- 1 Highway 401
- 2 Limehouse
- 3 Rattlesnake Point

PICKERING
GENERATING
STATION

NANTICOKE
GENERATING
STATION

Transmission of Power from Nanticoke to Pickering

June 1974

Original map published by
Solandt Commission, March 1974

The Solandt Recommended Route—Diagrammatic Alignment

Government Approved Modifications

A Toronto International Airport

Urban Areas

Parkway Belt Land Use Regulation Area
Ministry of Treasury, Economics and Intergovernmental
Affairs, August, 1973

scale in miles



TECHNICAL, ECONOMIC AND ENVIRONMENTAL ASSESSMENT
OF USED OIL RECOVERY AND DISPOSAL FOR ONTARIO

Dr Peter Cukor
Teknekron, Inc.
Project Manager

March, 1976

TEKNEKRON, Inc.
Energy and Environmental Engineering Division
Berkeley, California

STUDY SPONSORED BY:

Energy Management Program
Ministry of Energy
Province of Ontario

Project Director:
Richard Slocum
Ministry of Transportation
and Communications
Downsview, Ontario

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Disclaimer

While this research was sponsored under the Energy Management Program, we do not assume responsibility for its accuracy or its conclusions.

The public is encouraged to review and comment on the contents of this report.

Teknekron, Inc.

2118 MILVIA STREET
BERKELEY, CALIFORNIA 94704 • (415) 848-1464

March 25, 1976

Mr. Richard Slocum
Project Director
Ministry of Transportation
and Communications
1201 Wilson Avenue
Room 314, Central Building
Downsview, Ontario M3M 1J8

Dear Mr. Slocum:

RE: Waste Oil Recycling Study

Teknekron, Inc., is pleased to submit the attached report, "Technical, Economic and Environmental Assessment of Waste Oil Recovery and Disposal." This report represents the completion of Tasks I-X specified in Section 2.1 of the Memorandum of Agreement dated 29th August, 1975, between Teknekron and the Minister of Transportation and Communications.

We believe that the results of this study represent a significant advancement in the state of knowledge regarding used oil recovery and provide a basis upon which sound decisions concerning waste oil policy in Ontario can be made.

Let me add that I have very much enjoyed working with you, Kent Charters, Harold Fromm, Paul Pinnington, and Bob Phoenix. The guidance provided by yourself and the other members of the Waste Oil Committee was essential to the completion of this effort. I hope that we may have the opportunity to work together in the future.

Yours sincerely,

Peter M. Cukor

Peter M. Cukor, Ph.D.
Project Manager
Energy and Environmental
Engineering Division



WASHINGTON, D.C.
BERKELEY, CALIFORNIA

ACKNOWLEDGEMENT

A number of officials of the Ontario Government made important contributions to the completion of this study. Teknekron would like to acknowledge the assistance of:

Mr. Richard Slocum, Ministry of Transportation and Communications, who served as Project Director and provided valuable guidance in all aspects of this project.

Mr. Kent Charters, Ministry of Transportation and Communications, who provided estimates of waste oil availability and direction and assistance in the assessment of lube oil markets and economics of re-refining.

Mr. Harold Fromm, Ministry of Transportation and Communications, who provided direction and assistance in the survey of re-refining technology.

Mr. Paul Pinnington, Ministry of Energy, who provided contacts with representatives of the petroleum industry and coordinated the survey of major lube oil marketers.

Mr. Robert Phoenix, Ministry of Environment, who provided details of pertinent environmental criteria in Ontario and information on regulatory authorities in the Province.



TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY -----	x
1. SURVEY OF AVAILABLE RE-REFINING TECHNOLOGY -----	1
1.1 Introduction -----	1
1.2 Manufacture of Lubricating Oils -----	1
1.3 Waste Lube Oils -----	3
1.3.1 Re-Refining Waste Lube Oils -----	3
1.3.2 Available Technology -----	4
1.4 Plant Design Assumptions -----	11
1.4.1 Feed Composition -----	11
1.4.2 Yields -----	12
1.4.3 Chemical Consumption -----	12
1.4.4 Plant On-Stream Factor -----	12
1.4.5 Plant Capacity -----	13
1.5 Material Balance -----	13
1.6 Equipment Sizing -----	16
1.7 Offsites -----	16
1.8 Tankage -----	16
1.9 Waste Streams -----	17
1.10 Other Waste Streams -----	20
1.11 Utilities -----	22
1.12 Energy Comparison -----	22
1.13 Product Consumption -----	25
1.14 Technical Comparison -----	27
1.15 Industrial Oil -----	30
1.16 Antifreeze -----	33
References -----	36
2. RE-REFINING PRODUCT COST AND QUALITY -----	37
2.1 Introduction -----	37
2.2 Methodology of Assessment -----	39
2.3 Major Input Data and Assumptions -----	43
2.4 Base Case and Variant Cases: Calculations and Analysis -----	51
2.5 Ranking of Processes and Design and Operation Variants -----	86
2.6 Re-Refining Product Quality -----	88
2.6.1 Introduction -----	88
2.6.2 Summary -----	90
2.6.3 Lubricating Oil Tests and Their Significance -----	93
2.6.4 Discussion of Test Results -----	97
2.6.4.1 Reference Oils -----	97
2.6.4.2 Acid/Clay Process -----	97
2.6.4.3 Distillation/Hydrotreating Process -----	99



TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
2.6.4.4 Distillation/Clay Process -----	99
2.6.4.5 Unknown Process -----	99
2.6.5 Summary -----	100
3. ENVIRONMENTAL IMPACTS OF BY-PRODUCTS OF WASTE OIL RE-REFINING PROCESS -----	102
3.1 Introduction -----	102
3.2 Summaries of Re-Refining Process -----	104
3.2.1 Acid/Clay -----	104
3.2.2 Extraction/Acid/Clay -----	105
3.2.3 Distillation/Clay -----	105
3.2.4 Distillation/Hydrotreating -----	106
3.3 Overview of Process By-Products -----	106
3.4 Detailed Estimates of Re-Refining By-Product Quantities -----	108
3.4.1 Acid/Clay Process -----	109
3.4.2 Extraction/Acid/Clay Process -----	109
3.4.3 Distillation/Clay Process -----	110
3.4.4 Distillation/Hydrotreating Process -----	111
3.4.5 Lead Distribution -----	111
3.5 Implication of Preceding Analyses -----	112
3.5.1 Process Efficiency -----	113
3.5.2 Daily Processing Volume -----	113
3.5.3 Data Base Uncertainties -----	113
3.5.4 Non-Lead Waste Oil Contaminants -----	114
3.5.5 High Ash Residue -----	115
3.6 By-Product Transport Modes, Receptor Effects and Potential Damage Implications -----	115
3.6.1 Acid/Clay Process -----	116
3.6.2 Extraction/Acid/Clay Process -----	123
3.6.3 Distillation/Clay Process -----	124
3.6.4 Distillation/Hydrotreating Process -----	127
3.7 Conclusions -----	127
References -----	131
4. SURVEY OF ALTERNATIVE AVAILABLE TECHNOLOGY FOR DISPOSAL OR USE OF WASTE OIL, INCLUDING ANALYSIS OF ENVIRONMENTAL IMPACT -----	132
4.1 Waste Oil Disposal Alternatives -----	134
4.1.1 Biodegradation by Soil Microorganisms -----	134
4.1.2 Thermal Destruction -----	136



TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
4.2 Waste Oil Use Alternatives -----	137
4.2.1 Blending With Fuel Oil -----	137
4.2.2 Blending With Coal -----	145
4.2.3 Waste Oil as a Cement Plant Fuel -----	147
4.2.4 Used Oil as a Fuel in Municipal Waste Incinerators -----	149
4.2.5 Waste Oil Use in Asphalt Manufacture -----	152
4.2.6 Waste Oil as a Road Dust Suppressant -----	154
4.2.7 Blending With Diesel Fuel -----	170
4.3 Comparative Summary of Alternative Technologies -----	171
4.3.1 Fuel Applications -----	171
4.3.2 Use of Waste Oil in Asphalt Manufacture -----	174
4.3.3 Road Oiling -----	174
4.3.4 Blending With Diesel Fuel -----	174
4.4 Environmental Implications of Waste Oil PNA Content -----	174
References -----	179
5. DEMAND FOR LUBRICATING OIL IN ONTARIO -----	180
5.1 Introduction -----	180
5.2 Retail Sales -----	185
5.2.1 Vehicle Miles Traveled -----	185
5.2.2 Motor Oil Consumption Per Vehicle Mile -----	191
5.3 Non-Retail Sales -----	197
5.4 Total Sales of Lubricating Oil -----	209
5.5 Sales by Type of Oil -----	209
5.6 Sales by Type of Trade -----	213
5.7 Supply and Disposition of Lube Oils and Greases -----	217
5.8 Impact of New Refinery Capacity on the Lube Oil Supply in Ontario -----	227
6. SURVEY OF ATTITUDES TOWARD RE-REFINED PRODUCTS AND ASSESSMENT OF MARKET POTENTIAL -----	238
6.1 Introduction -----	238
6.2 Summary of Interviews with Commercial and Industrial Firms -----	241
6.2.1 Characteristics of the Interviewee and Firm -----	242
6.2.2 Lubricating Oils Purchased (Types and Volume) -----	243
6.2.3 Lubricating Oil Prices -----	246
6.2.4 Purchasing Process -----	246
6.2.5 Security of Supply -----	249
6.2.6 Potential Substitution -----	249
6.2.7 Use of Re-Refined Oil -----	250
6.2.8 Use of Synthetic Oil -----	252



TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
6.2.9 Waste Oil Disposal -----	253
6.2.10 Government Regulations -----	254
6.3 Summary of Numerical Analysis Pertaining to Commercial and Industrial Interviews -----	254
6.4 Summary of Interviews With Lubricating Oil Blenders -----	259
6.4.1 Introduction -----	259
6.4.2 Definition of an Independent Blending Company -----	259
6.4.3 Market Served by the Blender -----	259
6.4.4 Blenders in Ontario -----	260
6.4.5 Market Segmentation in Ontario -----	260
6.4.6 Volumes of Base Lubricating Oils Required -----	261
6.4.7 Prices Paid for Base Lubricating Oils -----	263
6.4.8 Base Lubricating Oil Specifications -----	263
6.4.9 Attitudes and Knowledge--Re-Refining and Recycling -----	264
6.5 Major Marketing Channels in Ontario and Summary Assessment of the Potential Market for Re-Refined Products -----	265
6.5.1 Introduction -----	265
6.5.2 Major Lubricating Oil Marketing Channels -----	265
6.5.3 Wholesale Market -----	267
6.5.4 Closed-Cycle Industrial Market -----	270
7. TECHNOLOGY FOR AN OPTIMAL RE-REFINERY -----	275
7.1 Introduction -----	275
7.2 Matrix Comparison of Re-Refining Process -----	275
7.3 Sensitivity Analysis of Matrix Comparison -----	278
7.4 Environmental Rating -----	282
7.5 Quality of Product Rating -----	283
7.6 Product Range Rating -----	284
7.7 Feedstock Availability and Market Assessment -----	286
7.8 Economic Rating -----	289
7.9 Conclusion -----	291



LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
Chapter 1		
1	Acid/Clay Process -----	6
2	Extraction/Acid/Clay Process -----	7
3	Distillation/Clay Process -----	9
4	Distillation/Hydrotreating Process -----	10
5	Dehydration/Clay Process -----	32
6	Antifreeze Refining Process -----	34
Chapter 2		
2.1	Sensitivity Analysis Distillation/Clay Process -----	70
2.2	Simplified Flow Sheet for the Lubricating Oil Cycle in Ontario -----	73
Chapter 3 (None)		
Chapter 4 (None)		
Chapter 5		
5.1	Sales of Lubricating Oils at Retail Pump Outlets -----	187
5.2	Actual and Projected Number of Passenger Automobile Registrations in Ontario -----	189
5.3	Non-Retail Sales of Lubricating Oils in Ontario -----	206
5.4	Sources of Supply of Lubricating Oils and Greases -----	223
5.5	Disposition of Lubricating Oils and Greases -----	225
5.6	Changes in Major Lube Flows From 1968 to 1970 in Response to Opening of New Refinery -----	231
Chapter 6		
6.1	Major Lubricating Oil Marketing Channels -----	266
Chapter 7		
7.1	Matrix Comparison of Re-Refining Processes -----	276



LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
Chapter 1		
1.1	Material Balance Summary -----	14
1.2	Tankage -----	18
1.3	Acid Sludge Analysis -----	19
1.4	Process Water Analysis, Acid/Clay Re-Refiner -----	21
1.5	Energy Comparison -----	23
1.6	Comparison of Re-Refining Alternatives -----	28
Chapter 2		
2.1	Sample of Discounted Cash Flow -----	41
2.2	Sample of Discounted Cash Flow With Depreciation and Tax Effect -----	42
2.3	Summary of Base Case Assumptions for Cases 1 Through 10 -----	45
2.4	Summary of Internal Computer Program Assumptions -----	50
2.5	Case 1 -----	53
2.6	Case 2 -----	54
2.7	Case 3 -----	55
2.8	Case 4 -----	56
2.9	Case 5 -----	57
2.10	Case 6 -----	58
2.11	Case 7 -----	59
2.12	Case 8 -----	60
2.13	Case 9 -----	61
2.14	Case 10 -----	62
2.15	Summary of Cases 1 Through 10 -----	66
2.16	Summary of Assumptions for Pricing Variants Related to Base Case 3 -----	67
2.17	Case 11 -----	68
2.18	Case 12 -----	69
2.19	Summary of Base Case Assumptions for Cases 13, 14 and 15 -----	76
2.20	Case 13 -----	78
2.21	Case 14 -----	82
2.22	Analysis of Typical Blending Additives to Base Stock Lubricants -----	83
2.23	Case 15 -----	87
2.24	Physical and Chemical Properties of Lubricating Oil Samples -----	89
Chapter 3	(None)	
Chapter 4	(None)	



LIST OF TABLES (Cont'd)

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
Chapter 5		
5.1	Lube Oil Sales in Ontario -----	181
5.2	Proportion of Total Lube Oil Sales in Ontario Covered by Questionnaire Respondents, By Year -----	183
5.3	Ontario Lube Oil & Grease Sales by Type of Lubricant -----	184
5.4	Sales of Lubricating Oils at (Retail) Service Stations -----	186
5.5	Passenger Automobile Registrations and Population for Ontario -----	188
5.6	Projections of Passenger Automobile Registration -----	190
5.7	Average Annual Mileage for Passenger Automobiles in the U.S. -----	192
5.8	Projected Average Annual Mileage -----	193
5.9	Passenger Automobile Vehicle Miles Traveled (VMT) in Ontario (Billions) -----	194
5.10	Oil Usage by Passenger Automobiles in the U.S. -----	196
5.11	Projected Oil Usage for U.S. Passenger Cars -----	198
5.12	Forecasts of Oil Use Per 1000 Vehicle Miles -----	199
5.13	Technological Prediction of Automotive Oil Demand -----	200
5.14	Forecasts of Retail Sales -----	201
5.15	Sales of Lubricating Oils Through Channels Other Than Retail Pump Outlets -----	203
5.16	Sales of Lubricating Oils by Sector of the Economy in 1973 -----	204
5.17a	RDP and Non-Retail Sales Forecasts -----	207
5.17b	Non-Retail Sales for Ontario Predicted Using All-Canada Forecasts to 1976 -----	208
5.18	Total Sales of Lubricating Oil -----	210
5.19	Percentage Distribution of Sales of Lubricating Oils & Greases by Year, For the Province of Ontario -----	211
5.20	Average Percentage Distribution of Sales of Lubricating Oils and Greases in Ontario and Canada -----	212
5.21	Forecast of Lubricating Oil Sales in Ontario by Type of Oil -----	214
5.22	Ministry of Energy--Teknekron Survey Response as a Percentage of Ontario Non-Retail Sales of Lube Oils and Greases -----	215
5.23	Sales of Lube Oils & Greases to Ultimate Consumers, Ontario, 1969-1974 -----	216



LIST OF TABLES (Cont'd)

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
5.24	Comparison of Questionnaire Responses With Statistics Canada Figures -----	218
5.25	Sales of Lube Oils and Greases as Percentage of Total Non-Retail Sales -----	219
5.26	Sales of Lube Oils and Greases as Percentage of Total Non-Retail Sales (Average Values for 1970-1973) -----	220
5.27	Estimated Sales of Lubricating Oil by Type of Trade -----	221
5.28	Supply and Disposition of Lube Oils and Greases in Ontario -----	222
5.29	Finished Lube Refining Capacity Compared With Refinery Production in Ontario -----	226
5.30	Finished Lube Capacity, By Plant in Canada, 1963-1975 -----	228
5.31	Impact of Shell Refining Facility in Quebec -----	230
5.32	Supply and Disposition of Lube Oils and Greases for All of Canada -----	234
Chapter 6		
6.1	Base Oil Requirements of the Blending Industry in Ontario in 1975 -----	262
6.2	Illustrative Example of Annual Sales Requirement for the Dehydration/Clay Process -----	272
Chapter 7		
7.1	Sensitivity Analysis of the Numerical Ratings in the Matrix -----	279
7.2	Overall Ranking of Re-Refining Process Using Different Weighting Factors for Relevant Criteria -----	280
7.3	Economic Rating Evaluation Criteria -----	290



EXECUTIVE SUMMARY

This study is an assessment of alternatives for the utilization of used lubricating oil. The study focuses on the technical, environmental and economic aspects of re-refining and provides an analysis of lube oil markets within the Province of Ontario.

The report contains seven chapters:

- Chapter 1 - Survey of Available Re-Refining Technology
- Chapter 2 - Re-Refining Product Cost and Quality
- Chapter 3 - Environmental Impact of By-Products of Re-Refining Processes
- Chapter 4 - Survey of Alternative Available Technology For Disposal or Use of Waste Oil Including Analysis of Environmental Impact
- Chapter 5 - Demand for Lubricating Oil in Ontario
- Chapter 6 - Survey of Attitudes Toward Re-Refining Products and Assessment of Market Potential
- Chapter 7 - Technology for an Optimal Re-Refinery

The following re-refining technologies are described in Chapter 1.

- Acid/Clay Process - Sulfuric acid reacts with, dissolves or settles waste oil contaminants; clay is utilized to remove any color bodies.
- Extraction/Acid/Clay Process - Propane is used to extract lube oil from waste oil. Sulfuric acid and clay are used to remove residual contaminants.
- Distillation/Clay Process - Waste oil is vacuum distilled. Lube oil distillates are treated with clay to remove residual contaminants.



- Distillation/Hydrotreating Process - Waste oil is vacuum distilled. Lube oil distillates are treated with hydrogen to remove residual contaminants.
- Dehydration/Clay Process - A simplified process for re-refining industrial used oil. The oil is heated to boil off water and light petroleum fractions. The dehydrated oil is treated with clay to remove residual contaminants.
- Antifreeze Recovery - The process consists of neutralizing free organic acid content, filtering for dirt and rust, and distillation for the recovery of ethylene glycol.

Each of the processes for re-refining used oil appear to be practicable, as they have been commercially or experimentally proven.

Chapter 1 establishes the technical basis for the economic, environmental and market assessments provided in the following chapters. Detailed flow diagrams are provided which indicate processing unit capacities, material flow rates, energy requirements and rates of by-product release. Detailed documentation of all design assumptions for each of the re-refining technologies are also provided.

Chapter 2 provides an economic analysis for each of the oil re-refining technologies described in Chapter 1. The economic analysis includes an evaluation of the initial capital investments and annual operating costs. Sensitivity analyses were performed for each re-refinery design concept to determine the effect of changes in plant design, capital cost, feedstock cost, etc. on the average unit cost of production and the after tax rate of return on investment. The economic modeling includes the current depreciation regulations and tax structure existing in Ontario.

The most economically attractive investment, based on the initial capital requirements, the average cost of production and the after tax rate of return on



investment, is the Distillation/Clay process, operating at 90 percent of capacity with a yearly intake volume of 5.5 million Imperial gallons of used lubricating oil.

The next most attractive is the Distillation/Hydrotreating process, utilizing comparable design and operating parameters. The Extraction/Acid/Clay and the Acid/Clay processes operating under the same conditions are either marginal or unprofitable investments.

The Dehydration/Clay process, operating at 90 percent of capacity with a yearly intake volume of 2 million Imperial gallons of used industrial oil, is an attractive investment. The after tax rate of return is comparable to that of the larger Distillation/Hydrotreating process. An analysis of the profitability of producing finished industrial oils by blending additives with re-refined base oils is also included.

The quality of re-refined base oils produced using three of the technologies under consideration was evaluated. Laboratory tests of the physical and chemical properties of commercially available re-refined oils revealed that all three technologies are capable of producing oils suitable for further use.

The environmental risks associated with alternative methods of disposal of the by-products of re-refining processes are analyzed in Chapter 3. On the basis of data developed in Chapter 1 for rates of by-product release and the relative risks of exposure to these wastes, the re-refining processes are ranked in order of decreasing potential environmental effect.

- Acid/Clay Process

Ranking based on the generation of the largest volume of lead-containing acid sludge and on the potential for sulfur oxide emissions.



- Extraction/Acid/Clay Process
Ranking based on reduced use of sulfuric acid with consequently lower generation of acid sludge and of sulfur oxides. Although the sludge contains relatively less lead, this is offset by the generation of high ash residue which contains lead.
- Distillation/Clay Process
Ranking based on elimination of sulfuric acid as a process ingredient with consequent elimination of acid sludge and sulfur oxide emissions.
- Distillation/Hydrotreating Process
Ranking based on the elimination of spent clay as a waste by-product. This is considered to be only a marginal advantage over the Distillation/Clay process because the spent clay is a space-occupying nuisance rather than a serious environmental hazard.
- Dehydration/Clay Process
Ranking based on an operation mode of re-refining only segregated industrial waste oil which does not contain lead. Use of caustics for additive removal is not required.

Chapter 4 provides a review of available technologies for disposal or use of waste oil, including analysis of environmental impacts.

The "disposal" methods reviewed are:

- Biodegradation by soil microorganisms
- Thermal destruction without useful heat recovery

The "useful" or potential applications of waste oil examined are:

- Blending with fuel oil
- Blending with coal
- Use as a fuel in cement plants
- Use as a fuel in municipal waste incinerators
- Use in asphalt manufacture



- Use as a dust suppressant road oil
- Blending with diesel fuel

Comparative evaluations of possible environmental impacts for each alternative are provided. Three specific highlights should be noted.

- Fuel applications - The blending of waste oil with fuel oil or coal and use in municipal incinerator facilities give rise to concern regarding atmospheric emissions. In all of these fuel uses, the lead is almost totally volatilized, thus posing the likelihood of its emission to the atmosphere. The major difference among the alternatives is the degree to which ambient lead concentrations are limited either by the use of tall stacks or pollution control devices. The key question is whether resulting ambient concentrations represent hazards to health. Although existing data suggest that ambient lead concentrations will not exceed current Ontario criteria, any disposal method which releases lead to the environment should be viewed with great caution.
- The use of waste oil as a cement plant fuel is particularly attractive, as nearly all of the lead contained in the waste oil becomes incorporated in the clinker and in the conditioning tower solids.
- Considerable attention is devoted to analysis of the environmental impacts of road oiling. The environmental hazards which are, or may be, associated with this alternative cannot be quantified except in the context of the specific conditions under which it is employed. Under some conditions, road oiling may be environmentally safe. Under other conditions, there could be significant risk to people, plants and animals. The specific conditions are outlined in the text. Recommendations are provided for further research to resolve these uncertainties.

Chapter 5 provides a ten year forecast of demand in Ontario for lubricating oil products. Demand projections by type of oil and end use are included. The following table summarizes the demand forecast (in millions of Imperial gallons) for Ontario:



	<u>1975</u>	<u>1980</u>	<u>1985</u>
Automotive Oils	43.3	54.2	69.5
Industrial Oils	49.9	62.4	79.9
Totals	93.2	116.6	149.4

Demand projections were based on historical relationships between lube oil consumption, vehicle miles traveled and industrial activity. A portion of the data required for these analyses were obtained from major oil companies with the assistance of the Ministry of Energy.

An analysis is provided of the impact of the currently planned expansion in lube oil refining capacity on the Ontario lube oil market and the implications of this new capacity for a large scale re-refinery. A major expansion in the production of virgin base oils would extensively alter the market balance, both in Ontario and in all of Canada. This alteration could pose a substantial threat to the profitability of a large scale re-refinery.

Chapter 6 presents the results of a survey of attitudes toward the use of re-refined products. Based on this survey and the demand forecasts of Chapter 5, an assessment of market penetration of re-refined oils is provided.

Preliminary consultation of census publications suggested that the time and available funds would be best spent in studying large users of lube oils in a few key industries, e.g., steel, fleet trucking, industrial tools and parts, etc., and independent blenders who sell finished lube oils in automotive and industrial markets. Interviews were held with 31 individuals representing 22 firms.



The interviews focused on:

- Characteristics of interviewee(s) and firm
- Types and volumes of lubricating oils purchased
- Lubricating oil prices
- Purchasing process
- Security of supply
- Potential substitution
- Use of synthetic oil
- Use of re-refined oil
- Disposal of waste oil
- Government regulations

The last part of Chapter 6 provides an analysis of major marketing channels and an assessment of the potential market for re-refined products. The commercial and industrial sectors and blenders are potential markets for re-refined products.

Interviews with blenders revealed that under present market conditions, these firms would be willing to purchase large volumes of re-refined oil, if the re-refiner could guarantee assurance of supply and maintenance of product quality. However, currently planned expansion of capacity for virgin lube oil production in Ontario poses a threat to stability of the wholesale lubricant market. In view of the projected growth rates for demand and producing capacity in Ontario and all of Canada, it is uncertain whether a large scale (5 million gallon per year) re-refinery could successfully compete in the wholesale market with suppliers of virgin lubricants.



Sales of industrial oils re-refined under closed-cycle conditions offer a degree of insulation from the expected competition resulting from planned expansions of refining capacity. Such insulation stems from the services offered, such as collection of waste products, blending of specific oils, technical assistance and contractual obligations. Sufficient waste oil supplies and appropriate channels of sale have been assessed to exist in order to support the operation of a small scale Dehydration/Clay process at an annual production level of 1.8 million Imperial gallons in Ontario.

Based on evaluations of the technology, economics and environmental impacts of available re-refining technologies, it is possible, after considering current and projected market conditions, to evaluate the five processes and recommend the optimal re-refining technology for Ontario. This recommendation is made in Chapter 7.

The criteria used for process evaluation are:

- Environmental Rating - Generation of by-products during the process operation based on:
 - Degree of hazard
 - Volume of waste per unit of product produced
- Quality of Product Rating - Effectiveness in removal of contaminants and additives, as well as effect of the process on desired product qualities.
- Product Range Rating - Ability of the process to produce selected product classifications, either neutral or bright stocks, and to provide a desired specific gravity and viscosity.



- Feedstock Availability and Market Assessment Rating - Ability to obtain the required quantity of waste oil feed for a specific desired operational capacity and the ability to market the product, either base oils to the wholesale market or finished oils blended with additives to final users.
- Economic Rating - Assessment of economic desirability based on the amount of initial capital investment required, unit cost to produce a gallon of product and estimated percentage rate of return after tax.

To account for the relative importance of each of the above criteria, weighting factors were assigned and each process was scored according to each criterion on a scale from one to ten. The total score for each process was calculated as the sum of the products of the weighting factors and the scores for each criterion. This permitted a numerical ranking of the five processes in order of overall desirability. Variations in the weighting factors assigned to each criterion were made in order to determine the sensitivity of the overall rankings to assumptions made regarding the relative importance of the criteria.

For all cases used in the sensitivity analysis, the Dehydration/Clay process was found to be the most desirable. Although either of the two distillation processes could also be highly desirable, uncertainty as to the availability of adequate volumes (5.5 million gallons per year) of waste oil feedstock reduced the rankings of these processes. The Dehydration/Clay process requires about 2 million gallons of industrial waste oil annually. Since this oil would be collected and re-refined under closed-cycle conditions (with contractual agreements between the re-refiner and his clients), the Dehydration/Clay re-refiner is insulated from competition provided by other markets (e.g., road oiling, cement plant fuel, etc.) for limited supplies of waste oil.



THEREFORE, THE RECOMMENDED OPTIMAL TECHNOLOGY FOR A RE-REFINERY IN ONTARIO BASED ON CURRENT AND PROJECTED CONDITIONS IS THE SMALL SCALE DEHYDRATION/CLAY PROCESS OPERATED ON A "CLOSED-CYCLE" CONTRACTUAL BASIS WITH INDUSTRIAL CLIENTS.

Should adequate supplies of feedstock be assured, either through location of additional sources of waste oil or through the provision of guaranteed allocations from currently known available supplies, the Distillation/Clay and Distillation/Hydrotreating processes would be the most desirable. Further assessment based on specific requirements of the operator would be needed to select between the two processes. However, even if an adequate supply of feedstock could be assured, increased competition in the wholesale market, due to planned large scale expansion of lube oil producing capacity in Ontario, may pose a threat to the profitability of a large scale re-refinery.



1. SURVEY OF AVAILABLE RE-REFINING TECHNOLOGY

1.1 Introduction

Lubricants conserve energy by reducing the energy needed for motion and by reducing the wastage of metals when two surfaces roll or slide against each other. Lubrication is accomplished by inserting a thin film of lubricant between the sliding surfaces substituting a lower fluid friction for a higher dry metal friction. If a lubricant is to perform satisfactorily, it must, in addition to reducing friction and wear, be able to carry away heat, prevent corrosion, disperse contaminants, inhibit foam formation, and remain intact under sever requirements.

To qualify as a good lubricant, oils must have the general performance characteristics of:

- Proper fluidity.
- Little viscosity change with temperature.
- Low freezing point.
- Thermal and chemical stability.

1.2 Manufacture of Lubricating Oils

Petroleum mineral oils are the most popular lubricants because of their relatively low cost and wide range of application. Since not all the components of petroleum crude oil are suitable for use as lubricating oils, the commercial production of lubricating oils from virgin crude consists of a series of processing steps to separate and concentrate those components having favorable characteristics, plus special steps to enhance their quality, followed by blending to meet the many special



service requirements. Finally, specialized chemical compounds are added to improve or impart desirable lubricating properties. Typically, refining virgin crude oil to produce lubricating oils consists of these processing steps:

- Distillation (fractionation) - Petroleum lube oils generally fall into the boiling range of 650° F. to 1,000° F. for so-called "neutrals" and above 1,000° F. for "bright stocks". Distillation is used to remove fractions boiling above and below this range and to produce neutral stock of different boiling ranges; for example, a light neutral, a medium neutral and a heavy neutral may have boiling ranges of 650° F. to 750° F., 750° F. to 850° F. and 850° F. to 1,000° F., respectively. (None of these boiling ranges is intended to be precise, and there is considerable overlap between adjacent stocks.)
- Solvent extraction - The material boiling above approximately 1,000° F. produced in the distillation step (vacuum residuals) can be treated with a solvent (commonly, propane) to extract the desirable high boiling range lube oil stocks (bright stock) from nondesirable components such as asphaltenes, resins and hydrocarbons combined with metals.
- Solvent treating - The stocks concentrated by distillation and solvent extraction of vacuum residuals can be treated with a solvent such as furfural to remove the nondesirable components and concentrate those which will satisfy the demand of good lubricating oils.
- Solvent dewaxing - Solvent dewaxing is used to remove the waxy components which, if present, would solidify due to the cold and could prevent the oil from reaching the areas of metal contact.
- Hydrogen or clay treating - The next refining step could be a treating process to remove oxygen- and nitrogen-containing compounds which, if left in the oil, could reduce the product quality by imparting to the oil a poor color and unsatisfactory color stability. The hydrogen-treating process accomplishes this by reacting hydrogen with these undesirable components (primarily, nitrogen compounds); the clay-treating process removes these components by absorbing them onto the clay which is removed from the oil by filtration. Hydrogen treating is generally replacing clay treating in modern lube oil plants.
- Blending and additives - The finished lubricating oil product is then produced by blending combinations of the various



neutrals and bright stock to meet the many viscosity requirements. Chemical compounds are added to enhance, improve or impart desirable characteristics to the final product.

1.3 Waste Lube Oils

In contrast to fuels, lube oils are only partially consumed during their lubricating service. Their quality is degraded by oxidation and decomposition of mineral oil and/or additives and by contamination by such components as gasoline, dirt, metallic particles and carbon. However, a high proportion of the used oil consists of the high-quality hydrocarbons contained in the original lube oil. Recovering these hydrocarbons from their decomposition products, contaminants and diluents so they can be reblended and reused provides the opportunity to reduce significantly the production of virgin lube oil. Because the refining steps to produce lube oil from petroleum crude are energy-intensive processes, any reduction in the volume of lube oil manufacture is accompanied by a significant reduction in the energy required to produce it. For example, a Teknekron study for the Environmental Protection Agency showed a net savings of about 20,000 Btu per gallon of lube oil re-refined over production of the same amount of lube oil from crude, assuming in both cases that all products other than the produced lubes are burned as fuel.⁽¹⁾

1.3.1 Re-refining Waste Lube Oils

The re-refiner uses the same unit processes, perhaps slightly altered, as the crude refiner. Re-refining is a less complex operation because (a) separation of hydrocarbons within a common boiling range is not made (having been done by the virgin lube refiner), thus reducing



the number of operations to remove impurities and contaminants and
(b) waste lube oils typically contain 70% to 90% recoverable lube oil.
Hence, the total volume of oil handled per volume of product is much
lower.

Re-refining consists of three sequential processing steps:

1. Light contaminants (gasoline and water) are removed by heating and flash off as an overhead product.
2. Heavy contaminants (decomposition and oxidation products, polymers, dirt and metallic particles) are removed. While many methods have been proposed to accomplish this separation, the commercially proven processes are treating with sulfuric acid, vacuum distillation or extraction using propane.
3. Finishing to improve color and oxidation stability by clay treating or by the newer process of hydrotreating (the catalytic addition of hydrogen).

1.3.2 Available Technology

Although many processes have been proposed for re-refining waste lube oils, only four processes appear to be practicable in that they have been commercially or experimentally proven. In the case of experimental concepts, these have been developed to the degree that a commercial plant could be built with confidence of success. These four processes are:

1. Acid/Clay Process. This is the most common process. At least 45 such plants are known to exist in Canada and the U.S. Use of this process is widespread in Europe as well. (2) This process is the oldest and is similar to the acid/clay-treating process which once was widely used in lube oil manufacture but which is now being supplanted by other methods in that industry. The basis of this process is adding



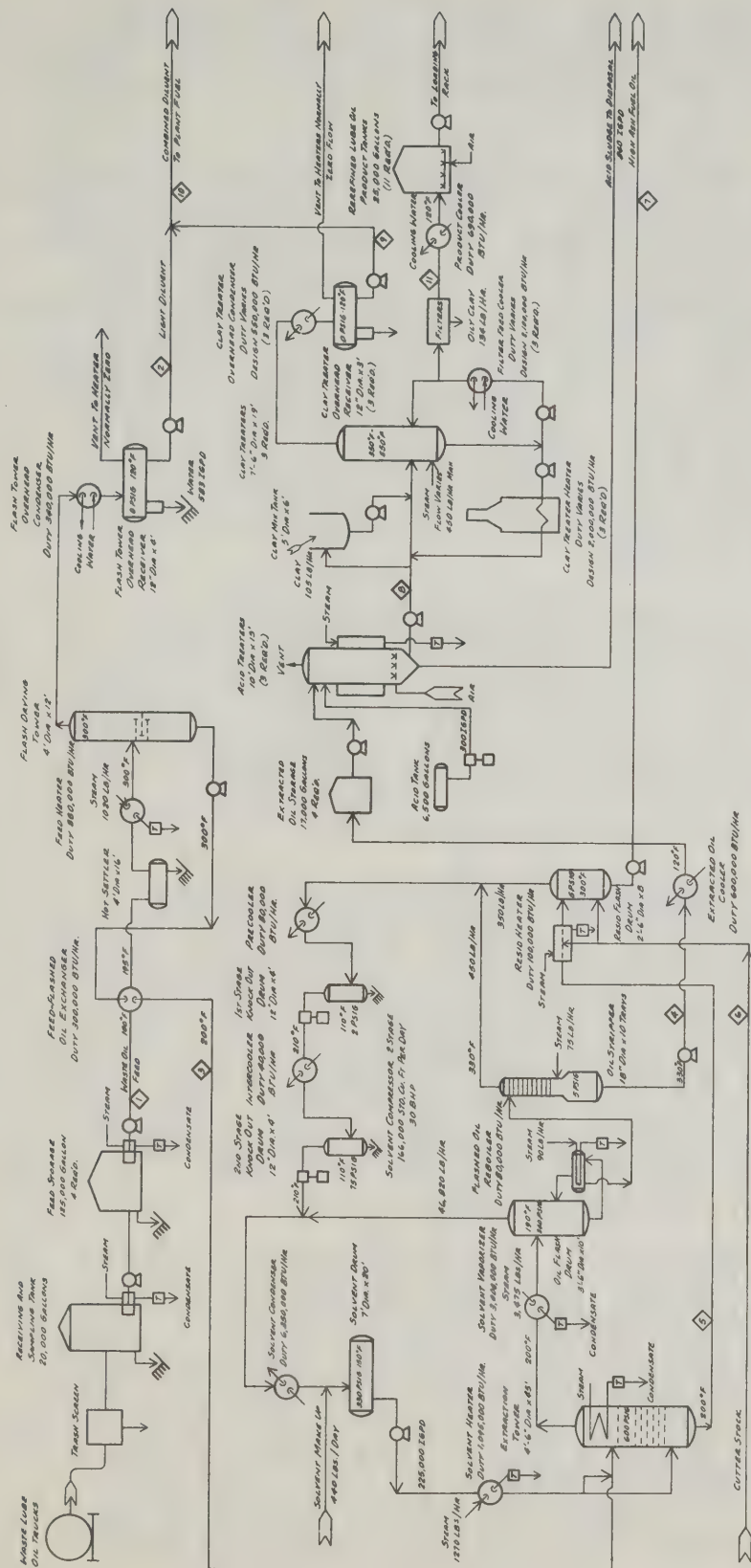
sulfuric acid which reacts with, dissolves or settles metal salts, asphaltics, aromatics, organic acids, polar compounds, dirt and metal particles to form a sludge which settles from the oil and is drawn off for disposal.


Figure 1 is a detailed flow diagram for the Acid/Clay process. The process consists of heating the waste oil to encourage any free water to settle. The waste oil is further heated to about 300° F. in order to vaporize the remaining water and any light oils such as gasoline. This mixture of liquid and vapor is charged to the flash tower where the vaporized (flashed) water and gasoline rise and are piped to a water-cooled heat exchanger. There they are condensed and the light oil is separated and recovered for use as plant fuel. The water-free waste oil is treated with sulfuric acid which combines with suspended solids and other impurities to form a sludge which is removed from the oil for disposal. The waste oil is then heated and clay is added to remove any color bodies remaining after the acid treating. The mixture is finally cooled and the clay removed by filtration for disposal. The product remaining is the re-refined lube oil.

2. Extraction/Acid/Clay Process. There are two Extraction/Acid/Clay plants operating in Italy and one under construction in Yugoslavia. The basis for this process is the use of propane to extract the lube oil stock from the degraded products, contaminants and additives. The extracted lube oils are then treated with acid and clay as in the Acid/Clay process. The impurities removed from the extracted oil are blended with fuel oil and disposed of as a high ash fuel oil.

Figure 2 is a detailed flow diagram for the Extraction/Acid/Clay Process. The waste lube oil is dehydrated as described in the Acid/Clay process. The dehydrated oil is then mixed with liquid propane and charged to an extraction tower operating at about 600 psig. The propane containing the dissolved oil is taken off the top of the tower, while propane insoluble residues are drawn off the bottom. The pressure on the extraction tower overhead stream is reduced to flash the propane, which is then reliquefied for reuse in the process. The extracted oil, free of propane, is sent to acid and clay treating as in the Acid/Clay process. The bottom stream is mixed with a small amount of fuel oil. The pressure is reduced to flash (vaporize) the propane from the residue. The propane is liquefied for reuse. The residue can be used as a high ash fuel oil in selected services capable of handling the metallic impurities.

3. Distillation/Clay Process. There are two plants in the United States using this process. The basis of this process is a combination of vacuum distillation to recover the lube oil



TEKNEKRON INC.		 4701 LANANIMERE ROAD 45BUNSTON, D.C. 20016 TEL: 800-368-1111 FAX: 800-368-1111										
MINISTRY OF		TRANSPORTATION & COMMUNICATIONS										
Figure 2												
EXTRACTION - ACID - CLAY												
PROCESS												
STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	
DESCRIPTION	WASTE LUBE OIL	LIGHT DILUENT	FLASHED OIL	EXTRACTED OIL	EXTRACTION RESIDUE (2)	CUTTER STOCK	HIGH ASM FUEL OIL (8)	ACID TREATED OIL	HEAVY DILUENT	COMBINED DILUENTS	RECOVERED LUBE OIL	
LOS /HR	62.11	275	5,596	5,405	291	94	305	5,215	90	365	5096	
TOPD	16,647	833	15,250	14,692	550	250	808	14,192	250	1,083	13,875	
"API	27.2 (1)	46.0	26.3	28.6	—	25.0	—	28.9	33.0	43.4	28.9	
SPECIFIC GRAVITY	8915 (1)	.797	.8970	.8833	1.25	.904	1.14	.8823	.8602	.8901	.8821	

(1) DRY BASIS
(2) VOLUMES & GRAVITY EXCLUDE ASH

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2115 MULVIA STREET
BERKELEY, CALIFORNIA 94704

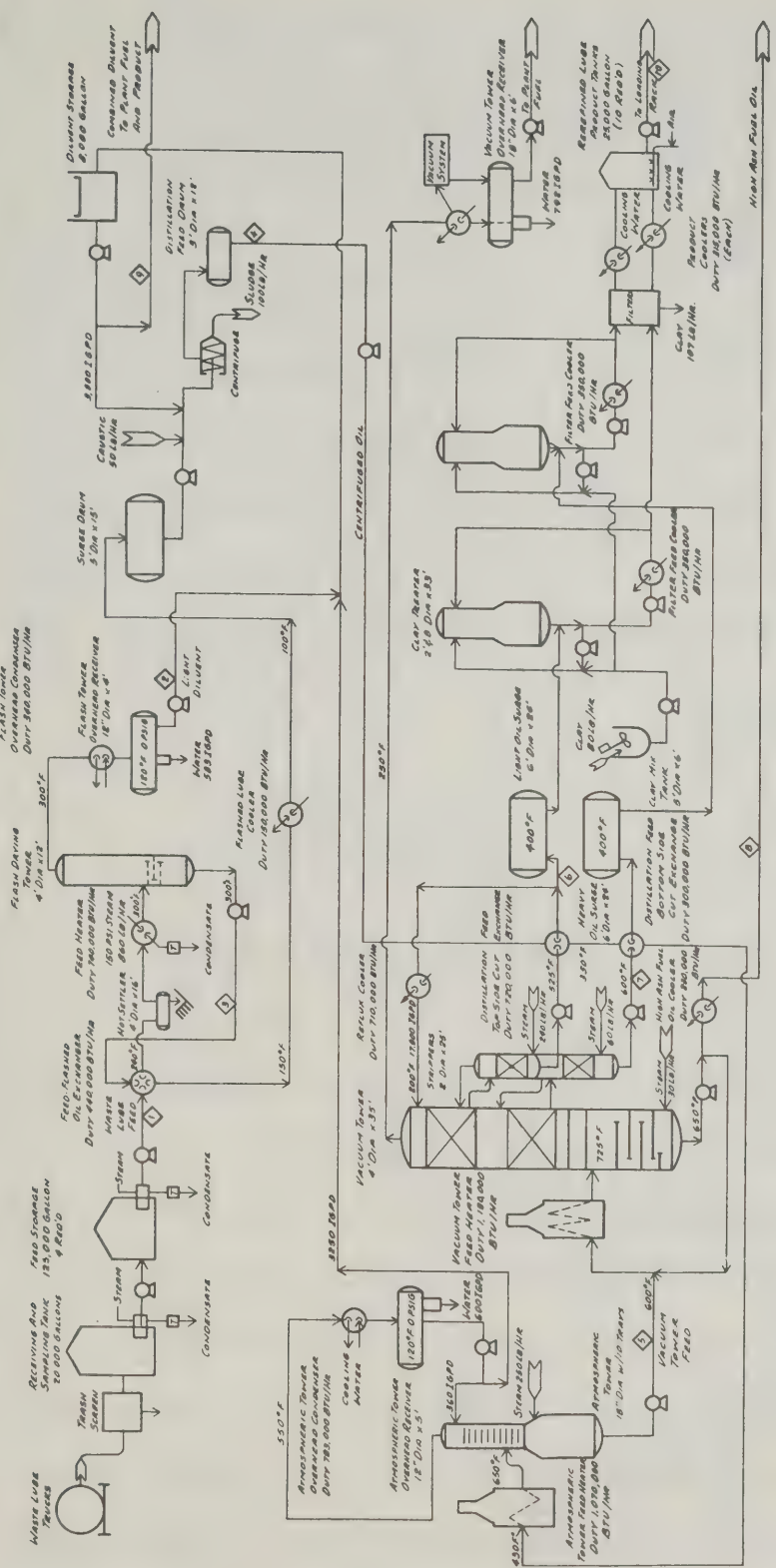
fraction from the waste oil, followed by clay treating for color improvement of the recovered oils. The suspended solids and other impurities are concentrated in the vacuum tower bottom stream. This material can be sold as a high ash fuel oil.


Figure 3 is a detailed flow diagram for the Distillation/Clay Process. The waste oil is flash-dried as described in the Acid/Clay process. The waste oil is then cooled, mixed with light oil and caustic, and charged to a centrifuge which removes precipitated solids as a sludge. The purpose of this step is to reduce corrosion and fouling in the following distillation steps. After centrifuging, the oil is charged to a distillation tower to recover and recycle the solvent. The oil is then charged to a vacuum tower. The lube oils are separated as distillation products from the suspended solids, degraded products, additives and other impurities. These are removed as a tower bottoms product and can be used as a high ash fuel oil.

If desired, the vacuum tower can produce varying grades of lube oils by extracting them from two or more locations (the Process Flow Diagram shows two side streams). These "side cuts" can have varying ranges of boiling points and viscosities. This option gives the re-refiner more flexibility in blending to meet different product specifications. The distillate lube oils are then treated with clay, cooled, filtered and sent to product storage.

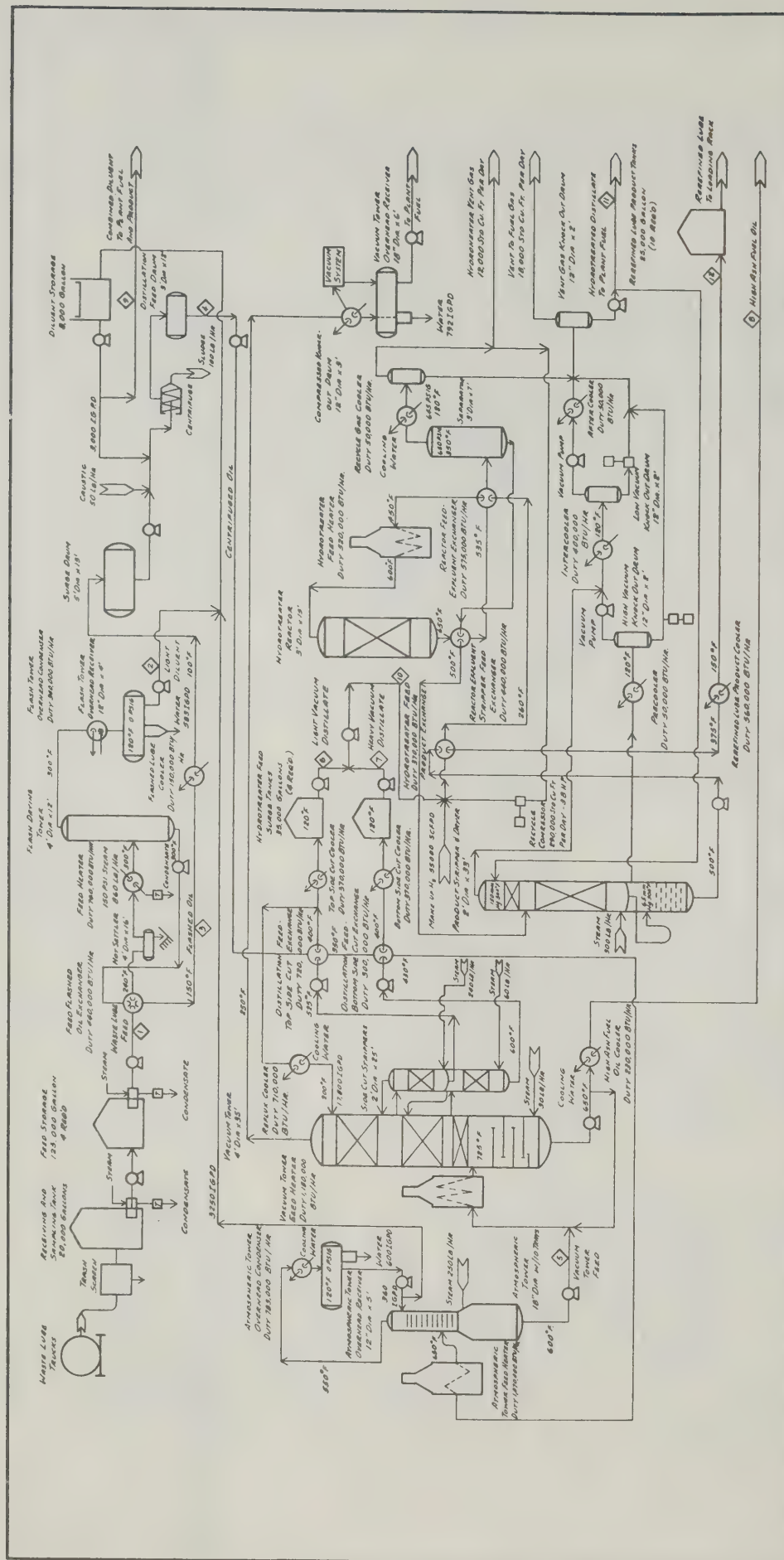
4. Distillation/Hydrotreating Process. Hydrotreating is a process used extensively for improving color and color stability in the manufacture of lube oils from petroleum. However, there is no plant in operation using this process for re-refining waste lube oils, although one is reported to be in the planning stage for location in Alberta. The basis of the process is the same as the Distillation/Clay process, except that the lube stocks are treated with hydrogen rather than clay. Hydrogen can either be purchased or manufactured at the re-refinery from steam and natural gas, using a small, self-contained, skid-mounted plant.


Figure 4 is a detailed flow diagram for the Distillation/Hydrotreating Process. The process is identical to the Distillation/Clay process through the vacuum distillation step. At this point the distillates from the vacuum tower are pumped to the hydrotreating unit where they are mixed with hydrogen, heated and charged to a catalyst-filled reactor. The effluent is cooled in the reactor and the unreacted hydrogen separated from the liquid lube oils and recycled. The treated lube oils are reheated to about 500° F. and stripped with steam under a vacuum to remove



 TEKNEKRON INC.		MINISTRY OF TRANSPORTATION & COMMUNICATIONS										Figure 3		DISTILLATION-CLAY PROCESS											
4470, BRIMLEY ROAD SCARBOROUGH, ONTARIO M1S 1T7 TEL: (416) 291-1111 FAX: (416) 291-1111		STREAM NUMBER		DESCRIPTION																					
		1		2		3		4		5		6		7		8		9		10					
		WASTE LUBE OIL		LIGHT DILUENT		FLASHED OIL		CENTRIFUGED OIL		VACUUM TOWER FEED		LIGHT VACUUM DISTILLATE		HEAVY VACUUM DISTILLATE		HIGH ASH OIL		COMBINED DILUENT		RESIDUE OIL					
		62.11		275		56.96		66.41		533.6		2438		2231		88.7		36.5		46.42					
		16,867		833		15,250		18,119		14,869		6,657		6,067		2,136		1,083		12,667					
		27.2 (1)		45.0		26.3		29.3		26.2		29.6		28.7		13.3		43.4		24.4					
		.8915 (1)		797		.8970		.8802		.8975		.8785		.8831		.9875		.8091		.880					
		SPECIFIC GRAVITY																							

(1) Dens. Basis



 TEKNEKRON INC.		4801 HANCOCK ROAD DALLAS, TEXAS 75246 BRIDGEVIEW, TEXAS 75815											
MINISTRY OF TRANSPORTATION & COMMUNICATIONS		Figure 4 DISTILLATION - HYDROTREATING PROCESS											
STREAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	
DESCRIPTION	WASTE LUBE OIL	LIGHT DILUENT	FLASHED OIL	UNWASHED OIL	VACUUM TOWER FEED	LIGHT VACUUM DISTILLATE	HEAVY VACUUM DISTILLATE	HIGH ASN FUEL OIL	COMBINED DILUENT	FEED TO HYDRO-REFINER	HYDRO-REFINER DISTILLATE	RECOVERED LUBE OIL	
185 / H.R	62.11	27.5	5696	6641	5556	2438	2231	887	365	4669	25	4162	
186 / P.D	16.67	833	15,250	18,119	14,869	6,847	6067	8136	1083	12,734	73	12,667	
*API	27.2 (1)	46.0	26.3	29.3	26.2	29.6	28.7	10.3	43.4	29.2	40.0	30.0	
SPECIFIC GRAVITY	.8915 (1)	.737	.8970	.8802	.8975	.8769	.8881	.8975	.8031	.8805	.8825	.8762	

(1) Der. Basis

(2) Stream As Streams (1) Combined, Hydrotreated Feed Cuts As Either (6) or (7) At 12.75% T&P.

residual hydrogen and any oils boiling below the range of the lube oils. The conditions in the hydrotreater reactor typically are: temperature, 650° F.; pressure, 650 psig; catalyst volume, one volume of catalyst per hourly volume of lube oil charge; and a hydrogen recycle rate of 800 standard cubic feet per barrel of lube oil charge.

1.4 Plant Design Assumptions

1.4.1 Feed Composition

The composition of waste lube oils can fluctuate widely, depending upon sources, frequency of oil change, severity of use, condition of engines, methods of collection and outside contamination by dirt and water. For this study, the feed composition was assumed to be:

	<u>Volume Percent</u>
Water diluent	3.5%
Gasoline diluent	5.0
Diesel diluent	1.5
Lube oils*	<u>90.0</u>
Total	100.0%

*Contains 1.5% noncombustibles

This study recognizes that waste oils frequently contain a much higher water content. The assumption was made that high water values consist mainly of free water (i.e., not in the form of oil emulsions) and that excess water will settle out if given the opportunity. The plant provides two places for free-water settling: first in the feed storage tanks (about 30 days' storage) and second--after heating to about 250° F. on the way to dehydration--in a hot settler where the wet lube oil spends about one hour. Here free water and even water held in weak emulsions should break free and settle out, leaving only tightly held water to be removed by vaporizing.



1.4.2 Yields

Yields for the four re-refining processes shown in the table below are based on information in "Waste Oil Recovery Practices, State of the Art", prepared for the State of Maryland Environmental Services and the U.S. Environmental Protection Agency.⁽³⁾

	<u>Acid/Clay</u>	<u>Extraction/ Acid/Clay</u>	<u>Distillation/ Clay</u>	<u>Distillation/ Hydrotreating</u>
On total feed	72.0%	83.25%	76.0%	76.0%
On lube oil fraction	80.0%	92.50%	84.4%	84.4%

1.4.3 Chemical Consumption

Amounts of chemicals used in the re-refining processes shown below are from the same study and are based on the lube oil content of the waste oil feed.

- 93% Sulfuric Acid
Acid/Clay - 1.0 pound per Imperial gallon
Extraction/Acid/Clay - 0.26 pounds per Imperial gallon
- Clay
Acid/Clay - 0.50 pounds per Imperial gallon
Extraction/Acid/Clay - 0.18 pounds per Imperial gallon
Distillation/Clay- 0.15 pounds per Imperial gallon
- Caustic
Distillation/Clay - 0.08 pounds per Imperial gallon
Distillation/Hydrotreating - 0.08 pounds per Imperial gallon
- Propane
Extraction/Acid/Clay - 0.08 pounds per Imperial gallon

1.4.4 Plant On-Stream Factor

The plant on-stream factor was assumed to be 90%. The plant operates at design capacity 90% of the time, or 330 days per year, which allows 35



days per year to rerun off-specification product, shut down for maintenance, and cover unexpected losses in capacity.

1.4.5 Plant Capacity

The four process flow diagrams, Table 1.1 (Material Balance Summary), the utility summary (Section 1.11), and Table 1.5 (Energy Comparison) are all based on collecting 5.5 million Imperial gallons of waste lube oils per year. At 90% operating factor, the daily feed is 16,666 Imperial gallons per on-stream day.

Generally, the larger the plant capacity, the lower the costs of producing a unit of product. The converse is also true, and in very small plants the unit costs tend to skyrocket. Thus, capital and operating costs favor larger plants. The re-refiner has a counteracting cost in that to collect more waste oils, he has to extend his pickup area until eventually these costs exceed any savings due to economics of scale in plant design and operations. The capacity of 16,666 Imperial gallons per day of charge was selected in order to balance the unit production costs of plants operating 24 hours a day, 330 days per year, against the volume of waste oils available at reasonable cost in a large metropolitan area.

1.5 Material Balance

Using the assumptions described above, material balances were developed for the four processes (refer to the material balance charts on each of the flow diagrams). The summary of these balances is shown on the process flow diagram for each process and also in Table 1.1.

TABLE 1.1

MATERIAL BALANCE SUMMARY

Item Number	Plant Inputs:	Acid/Clay	Extraction/ Acid/Clay	Distillation/ Clay	Distillation/ Hydrotreating
1	Feed--				
	Water	583.3*	583.3	583.3	583.3
	Light diluent	833.3	833.3	833.3	833.3
	Heavy diluent	250.0	250.0	250.0	250.0
	Used oil	15,000.0	15,000.0	15,000.0	15,000.0
	Total	<u>16,666.6</u>	<u>16,666.6</u>	<u>16,666.6</u>	<u>16,666.6</u>
2	Purchased fuel oil	-	828	-	-
3	Natural gas--standard cubic feet per day	-	-	-	42,000
4	93% sulfuric acid	783	300	-	-
5	Clay--pounds per day	6,000	2,520	1,920	-
6	Caustic--pounds per day	-	-	1,200	1,200
7	Propane--pounds per day	-	440	-	-
	Plant Outputs (excludes waste streams and fuel used):				
8	Re-refined oil	12,000	13,875	12,667	12,667
9	Light fuel	426	-	169	121
10	High ash fuel	-	808	2,136	2,136
	total liquid products	<u>12,426</u>	<u>14,683</u>	<u>14,972</u>	<u>14,924</u>

NOTES

Item Number

1. Feed-- Plant feed in Imperial gallons per on-stream day with the design composition of 3.5% water, 5.0% gasoline diluent, 1.5% diesel diluent and 90.0% waste lube oils.
2. Purchased fuel oil. In all the processes, the gasoline and diesel diluent fractions contained in the raw feed are recovered and used for plant fuel. This amount of recovered light distillates exceeds the plant fuel requirements, and the excess shows as light fuel product (line 9) in three processes--Acid/Clay, Distillation/Clay and Distillation/Hydrotreating. In the Extraction/Acid/Clay process, these recovered light distillates do not meet the plant fuel requirements and, in addition, fuel oil must be imported to dilute the residue from the extraction tower. Line 2 is the sum of additional fuel required plus dilution for the extraction tower bottoms.
3. Natural gas--42,000 standard cubic feet per day of natural gas are required for feed and fuel for the hydrogen manufacturing plant used only in the Distillation/Hydrotreating process.
4. 93% sulfuric acid--acid used in the Acid/Clay and Extraction/Acid/Clay processes.
5. Clay--amount of clay used in the three processes requiring it.
6. Caustic--amount of caustic used in the two Distillation processes in the centrifuging step between dehydration and distillation.
7. Propane--propane makeup to cover losses of solvent to product and leakage.
8. Re-refined oil--re-refined oil product from the plant.
9. Light fuel oil. The waste lube oils contain oil diluent from many sources such as gasoline leakage into the oil system in the automobile, diesel leakage in truck engines and spillage at service stations. These oils will have a boiling range lower than the lube oils, and are flashed or stripped from the lube oils in the process. They must be removed or the finished lube oil would not meet the flash point specification. These light oils can be used in the plant as fuel for heaters and boilers. Any excess above plant requirements can be sold as a nonspecification light fuel oil (they may have a low flash point) or possibly to a crude oil refiner who could rerun them (see line 2).

*All values are Imperial gallons per day except those for natural gas, clay, caustic and propane.

TABLE 1.1
(continued)

NOTES

Item Number

10. High ash fuel. High ash fuel is produced as the vacuum tower bottoms in the two distillation processes. Depending on the waste oil feed composition, this product could meet residual fuel flash point and viscosity specifications. However, since much of the metallic contaminants are concentrated in this stream, it will have to be marketed selectively to users who can accommodate the high ash content (10% to 25%). Cement kilns, some power plants and secondary lead-smelting reverberation furnaces for both energy and lead recovery are potential users.

High ash fuel is also produced in the Extraction/Acid/Clay process. The waste lube oil contaminants are concentrated in the solvent tower bottoms product. In order to pump and handle this stream, it will be necessary to dilute it with cutter stock. The sales problems discussed for the high ash fuel oil apply to this stream, which could be higher in contaminants since, in the Distillation process, some of the dirt and ash formers will have been removed in the centrifuges.



1.6 Equipment Sizing

Equipment sizes shown on the various process flow diagrams were determined by applying industry-accepted chemical engineering design principals to satisfy the requirements of operating conditions and material balance.

To cover the batch type of operations involved, the following assumptions were made in the Acid/Clay process:

- The acid- and clay-treating equipment is sized so that each shift would start a batch of one-third of the daily charge. This requires three acid-treating and three clay-treating vessels.
- A fourth acid treater is installed to provide more flexibility in case an oil requires unusually severe treating conditions.
- The Acid/Clay treating schedule is:

<u>Action</u>	<u>Hours</u>
Add acid and agitate	1 - 2
Settle and draw sludge	10 - 24
Transfer to clay treaters	1 - 2
Heat	4 - 8
Steam strip	4 - 8
Cool and add clay	2 - 8
Filter	2 - 4
Total	24 - 56

1.7 Offsites

Offsites are facilities which are not part of the treating process but which are necessary to support the operation of the plant. These include boilers for steam generation, electrical connections, office, equipment shelters and a cooling tower.

1.8 Tankage

Tankage is needed to provide flexibility in plant operation and to cover



nonuniform delivery of raw feed and pickup of finished products. Tankage included in this study for the various processes is shown in Table 1.2.

1.9 Waste Streams

Quantities of waste products generated in the four processes are summarized in the table below:

	<u>Acid/Clay</u>	<u>Extraction/ Acid/Clay</u>	<u>Distillation/ Clay</u>	<u>Distillation/ Hydrotreating</u>
Acid sludge--Imperial gallons per day	3,436	840	-	-
Oil and clay mixture-- pounds per day	7,920	3,220	2,570	-
Centrifuge sludge-- pounds per day	-	-	2,400	2,400
Process water--Imperial gallons per day	1,330	1,510	1,970	2,700

The acid sludge generated in the Acid/Clay and Extraction/Acid/Clay processes contains sulfuric acid, combustibles, lead, organometallics and other metals from the additives. Table 1.3 shows the composition of an acid sludge. Very few detailed analyses of this sludge are available for comparison, so this table may or may not be typical. The volume of sludge generated in a re-refining plant is generally much too small to be attractive economically for acid and metals recovery, so landfilling is the most common method of disposal.

Oily clay is generated in all of the processes except Distillation/Hydrotreating. Spent clay normally is disposed of as landfill. The following table shows the range of clay analyses for petroleum lube oil, which should be similar to re-refined lube oil clays.



TABLE 1.2

TANKAGE

Item Number	Service	Basis of Storage Volume	Volume*		
			Acid/Clay	Extraction/ Acid/Clay	Distillation/ Hydrotreating
1	Receiving	Two 7,500-gallon deliveries	20,000	20,000	20,000
2	Raw oil feed	30 days	500,000	500,000	500,000
3	Storage after dehydration	4 days	60,000	60,000	-
4	Storage after dehydration	10 days	-	-	130,000
5	Product	20 days	250,000	280,000	250,000
6	Total lube oils	64 days	830,000	860,000	900,000
7	Fuel	20 days	8,000	25,000	15,000
8	Centrifuge diluent	-	-	-	8,000
9	Sulfuric acid	4,000-gallon truck	6,500	6,500	-

NOTES

Item Number

1. Receiving. Raw lube oils are delivered to the plant by truck and are discharged into the receiving tanks where they can be sampled and then pumped to an appropriate raw feed storage tank.
2. Raw oil feed. The raw feed tanks provide about one month's storage.
3. Storage after dehydration. These tanks provide storage to cover the batch operation of the Acid/Clay process plus temporary out-of-phase operation of the dehydration and the following treating step. These tanks can also be used to store any finished product that does not meet specification and must be rerun. Four days' storage is provided in the Acid/Clay, Extraction/Acid/Clay and Distillation/Clay processes. An extra six days are provided in the Distillation/Hydrotreating process to allow independent shutdown of the hydro-treating unit for catalyst regeneration or replacement (line 4).
5. Product--20 days' storage of the re-refined lubes is provided.
6. Total lube oils. The total volume of storage for raw, intermediate and final lube oils is equivalent to about 65 days of operation (total of lines 1 through 5).
7. Fuel--Storage of 20 days' plant fuel requirement. If the light diluents in the raw feed exceed plant fuel demand, the excess would be sold from these tanks; if the light diluents do not meet plant fuel requirements as in the Extraction/Acid/Clay process, fuel will be purchased to maintain the inventory in these tanks.
8. Centrifuge diluent. An 8,000-Imperial-gallon tank was provided for the centrifuge diluent.
9. Sulfuric acid. The sulfuric acid tank was sized to accommodate a 4,000-Imperial-gallon delivery when about half full.

*These volumes are based on handling 16,666 Imperial gallons of waste oil feed each day for 330 days/year.

TABLE 1.3
ACID SLUDGE ANALYSIS⁽¹⁾

WEIGHT PERCENT ANALYSIS:

	<u>Diesel</u>	<u>Crankcase</u>
Percent acid	47.50%	40.80%
Ash sulfate	4.45%	11.26%
Sulfur ⁽²⁾	14.90%	14.10%
Sulfur	15.10%	13.30%
Combustibles	30.00%	42.00%

ELEMENTAL ANALYSIS (PARTS PER MILLION):

Cu	40	40
Al	40	140
Fe	500	1,100
Si	800	1,400
Pb	1,100	20,000
Ag	14	-
Zn	200	2,100
Ba	400	1,300
Cr	190	50
Ca	12,600	6,400
Na	200	4,000
P	1,000	4,300
B	40	50
Ni	10	30
Sn	38	30
Mg	70	1,000
TOTAL	17,139	41,940
Sulfate ash ⁽³⁾	5.35%	9.39%

SOLUBLE IN WATER:

	<u>Weight %</u>
Ash	4.2%
Acid	27.0%

INSOLUBLE IN WATER:

Ash	8.4%
Acid	1.6%
Volatiles ⁽⁴⁾	0.8%
Lube oils ⁽⁵⁾	15.5%
Polymers	15.6%
Other polar	1.8%
Asphaltenes and resins	24.4%
TOTAL	99.3%

DENSITY: 10 pounds/cubic feet

pH: 0.1

Viscosity SSU:

175° F.	4,000,000
105° F.	457,000
125° F.	150,600

- (1) "Waste Oil Study", Report to the Congress authorized by Section 104(m) Public Law 92-500, April 1974.
 (2) Calculated from acid assuming H₂SO₄.
 (3) Calculated from elemental analyses.
 (4) Naphthenes, paraffins, aromatics.
 (5) 150° C. at 1 mm Hg.



	<u>Average</u>	<u>Range</u>
Btu/pound	5,000	1,000 - 9,250
Particle size--Sieve No.	170	30 - 300
Volatile--weight percent	14.0%	0.0% - 55.0%
Ash--weight percent	53.0%	0.0% - 99.8%
Water--weight percent	8.0%	0.0% - 36.0%
Oil--weight percent	19.0%	1.0% - 45.0%
pH	5.6	3.5 - 7.5

Centrifuged sludge is generated in the two distillation processes and can contain caustic, sodium silicate, lead and other metals and oil. Selected landfill is the most common disposal method.

Process water sources are boiler blowdown, cooling tower blowdown, condensed process stripping steam and water decanted or flashed from the feed. In addition, there will be oily water runoff from paved areas during cleanup and rainstorms. When municipal treatment facilities are available, the re-refiner generally needs only to install oil-water separators and possibly neutralization facilities. If complete treatment prior to discharge is required, more sophisticated facilities are needed which can best be determined after selecting the process and identifying the contaminants which will appear in the wastewater. Table 1.4 is an analysis of process water taken at an Acid/Clay re-refining plant. There was some difficulty in obtaining the samples, and since there are no samples from other plants for comparison, it is not known whether these samples are typical or not.

1.10 Other Waste Streams

All the plants will occasionally produce a variety of other residues, such as tank-cleaning wastewater-treating sludges. These generally are disposed of with refuse or as landfill.



TABLE 1.4
PROCESS WATER ANALYSIS
ACID/CLAY RE-REFINER (1)

	<u>Clay Contactor</u> <u>Overhead Receiver</u>		<u>Cooling</u> <u>Tower</u> <u>Blowdown</u>	<u>Plant</u> <u>Discharge</u>
	<u>11:30 a.m.</u>	<u>12:30 p.m.</u>		
BOD mg/l (2)	2.7	4.0	4.0	6.0
COD mg/l (3)	31,806(4)	16,943(4)	43	792
Oil mg/l	3.023(4)	3.629(4)	9	168
Phenols mg/l	92(5)	84	4	89
pH	6.0	6.1	6.5	4.1
Nitrates mg/l	0.81(4)	0.64(4)	N.1	0.25
Total solids mg/l	959	2,256	180	493
Dissolved solids mg/l	511	931	172	483
Suspended solids mg/l	394	401	7	4
Emission spectral survey				
"Strong"	Fe,Mg	Fe,Mg	Mg,Ca	Fe,Mg
	Ca,Na	Ca,Na	Na	Ca
"Medium"	Si	Si	-	Na

- (1) "Waste Oil Recycling and Disposal," National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, Publication No. EPA-670/2-74-052, August 1974.
- (2) Biological oxygen demand.
- (3) Chemical oxygen demand.
- (4) Samples may have been contaminated with oil.
- (5) 150 gm/l phenolic compounds reported by outside laboratory.

Air pollution should not be a major problem in any well-designed plant.

1.11 Utilities

Utility requirements, when charging 16,666 Imperial gallons per day of raw waste oil to each of the four processes, are shown below. The fuel requirement includes that required to produce steam in the plant boiler; the steam figure is shown only to indicate the average amount of steam generated. Makeup water supplies the process needs of the boiler and cooling tower and does not cover water used to clean up or hose down the work area. Natural gas is used in the Distillation/Hydrotreating process for feed and fuel for hydrogen manufacture.

	<u>Acid/Clay</u>	<u>Extraction/ Acid/Clay</u>	<u>Distillation/ Clay</u>	<u>Distillation/ Hydrotreating</u>
Power (kWh)	55	200	55	80
Steam--pounds/hour	1,775	6,960	1,840	2,240
Makeup water--Imperial gallons/day	8,750	28,830	10,100	13,670
Fuel				
Natural gas--standard cubic feet/day	-	-	-	42,000
Heaters and boilers-- Imperial gallons/day	675	1,646	914	1,159

1.12 Energy Comparison

The four re-refining processes have different fuel and power demands and different recoveries of feed as either finished lube oil or high ash fuel. Table 1.5 compares total energy by combining the potential energy of feed, products and external energy. In this comparison the potential energy is the gross heat of combustion (high heating value) of the various streams. Diluent gasoline and diesel in the raw oil are excluded, as is diluent fuel for the extraction tower bottoms produced in the Extraction/Acid/Clay



TABLE 1.5

ENERGY COMPARISON
(16,666 Imperial Gallons Per Day)

	<u>Acid/Clay</u>	<u>Extraction/ Acid/Clay</u>	<u>Distillation/ Clay</u>	<u>Distillation/ Hydrotreating</u>
1. Re-refined oil, Imperial gal./day	12,000	13,875	12,667	12,667
	---thousand Btu per hour---			
2. Feed potential	106,080	106,080	106,080	106,080
3. Product potential	85,200	98,510	89,800	89,570
4. Fuel potential	-	3,770	14,670	14,670
5. Total recovered	85,200	102,280	104,470	104,240
6. Potential lost	20,880	3,800	1,610	1,840
7. Natural gas	-	-	-	1,740
8. Fuel	4,350	11,450	6,040	7,780
9. Power	550	2,000	550	800
10. Total consumed	4,900	13,450	6,590	10,320
11. Lost plus consumed	25,780	17,250	8,200	12,160
	---Btu per gallon of product---			
12. Potential lost	41,760	6,570	3,050	3,490
13. Consumed	9,800	23,240	12,490	19,550
14. Lost plus consumed	51,560	29,840	15,540	23,040

NOTES

Item Number

1. Re-refined oil--volume of product, Imperial gallons per day.
2. Feed potential--potential energy in the lube oil fraction of the feed at 169,700 Btu per Imperial gallon.
3. Product potential--potential energy in the re-refined oil products. Gross heating value of the product is:

	<u>Btu per Imperial gallon</u>
Acid/Clay	170,400
Extraction/Acid/Clay	170,400
Distillation/Clay	170,150
Distillation/Hydrotreating	169,700

4. Fuel potential. In the Extraction/Acid/Clay process, this is the gross heating value of the extraction tower residue which is in the high ash fuel product (excludes diluent). In the distillation processes, it is the gross heating value of the vacuum tower bottoms which is in the high ash fuel product. In the Acid/Clay process, the corresponding residual stream is in the acid sludge and is not recoverable as a fuel.



TABLE 1.5
(continued)

NOTES

Item Number

5. Total recovered. Total potential in product streams (total of lines 3 plus 4).
6. Potential lost. Potential energy in feed not recoverable in products (line 2 minus line 5).
7. Natural gas. Natural gas used in the Distillation/Hydrotreating case for hydrogen manufacture.
8. Fuel. Total fuel used in the process for process heaters and boiler steam generation.
9. Power. Electric power converted from kWh to Btu/hour. The conversion factor is kWh times 10,000. This conversion factor is a rounded-off value of 3,415 Btu per kWh divided by the product of all the efficiencies in converting fuel at a power station.
10. Total consumed. Total external energy applied to the process (total of lines 7, 8 and 9).
11. Lost plus consumed. Total potential energy lost between feed and products plus external energy (line 6 plus line 10).
12. Potential lost. Potential energy lost between feed and products expressed as Btu per Imperial gallon on re-refined product (line 6 times 24 hours per day divided by line 1).
13. Consumed. Energy consumed by the process expressed as Btu per Imperial gallon of product (line 10 times 24 divided by line 1).
14. Lost plus consumed. Total potential energy lost between feed and products plus external energy expressed as Btu per Imperial gallon of product (line 11 times 24 divided by line 1; also, line 12 plus line 13).

Several interesting comparisons show up in Table 1.5. Line 5 shows that the recovery of potential energy in the Extraction/Acid/Clay, Distillation/Clay and Distillation/Hydrotreating processes is quite high (96.4%, 98.5% and 98.3%) compared to the Acid/Clay process (80.3%) because of its high loss to sludge. The converse of this appears in line 6.

Line 10 shows that the Acid/Clay process has the lowest external energy requirement; and the highest is in the Extraction/Acid/Clay process, with the two Distillation processes in between. The totals of potential lost, plus external energy (line 11), favor the Distillation/Clay process. The Acid/Clay process is the most unfavorable.

Lines 12, 13 and 14 express these same conclusions on the basis of a gallon of product lube oil. Even though the Acid/Clay process has the lowest external energy input, it has the highest total loss when considering the potential energy loss of material not appearing as a product. The Distillation/Clay process is the most attractive when compared on this basis.



process. This exclusion does not affect the results, since the streams either pass in or out unchanged or are counted as fuel consumed.

1.13 Product Comparison

Starting with a common waste oil feed, the four processes would produce re-refined lube oils of slightly different physical characteristics because of the different treating steps employed. As outlined earlier, lube oils generally are composed of mixtures of "neutrals" and "bright stocks." The primary petroleum re-refining step is vacuum distillation. In this step the neutrals are distillate cuts--i.e., they have been vaporized and recondensed. The boiling range of the bright stocks is so high that they do not distill in the vacuum tower and are recovered by extraction from the nonvaporized vacuum tower bottoms. Neutrals produced from the same crude would have a lower boiling range, lower specific gravity (higher °API) and lower viscosity than the corresponding bright stocks.

The Acid/Clay and Extraction/Acid/Clay processes generally recover lube oil neutrals and bright stocks in proportion to their mixture in the raw oil. The two distillation processes would recover only the neutrals, since the bright stocks would not vaporize and would end up in the high ash fuel. In addition, hydrotreating adds hydrogen to the oils, thus slightly reducing the specific gravity. The following table shows how the specific gravities and viscosities could be expected to vary for the four processes when treating a common waste lube oil.



	<u>Acid/Clay</u>	<u>Extraction/ Acid/Clay</u>	<u>Distillation/ Clay</u>	<u>Distillation/ Hydrotreating</u>
		<u>Specific Gravity</u>		
°API ⁽¹⁾	28.9	28.9	29.3	30.0
Viscosity				
100° F.--SUS ⁽²⁾	462.0	462.0	370.0	370.0
Centistokes	100.0	100.0	80.0	80.0
210° F.--SUS ⁽²⁾	60.0	60.0	56.5	56.5
Centistokes	10.3	10.3	9.4	9.4

(1) °API--measure of specific gravity at 60° F.:
specific gravity 60° F./60° F. = $\frac{141.5}{°API + 131.5}$

(2) SUS--viscosity measurement, Saybolt Universal Seconds

All four processes should adequately remove contaminants so that the recovered lube oils will satisfy color, chemical stability and viscosity specifications equivalent to those for virgin lube oils. Any waste oil contaminant or lube oil additive (dispersants, viscosity index improvers, etc.) passing through the treating steps must have physical and chemical properties similar to lube oil. To pass through the Acid/Clay process, it must be nonreactive to sulfuric acid and not absorbed by clay. In addition, it must be propane-soluble in the Extraction/Acid/Clay process. To pass through the Distillation/Clay process, a compound should have a boiling range of between 650° F. and 1,000° F. and be inert to the attractions of clay. In the Distillation/Hydrotreating process, the compound should have the same boiling range and not be reacted by high-pressure hydrogen. Most additives would fail to meet all of these combinations or requirements and can be expected to be rejected by the treating processes. However, because of the increasing amounts and changing compositions of lube oil additives, and because of the lack of any publications specific to this subject, there is some uncertainty about the amounts of



any additive remaining in the re-refined oil. The question is whether enough remains to affect adversely the performance of the lube oil after blending with other lube stocks and new additives. When testing plant products, it should be ascertained whether carry-through of any additive requires further study or plant modifications.

1.14 Technical Comparison

The advantages and disadvantages of the four processes are summarized in Table 1.6. The unit operations of solvent extraction, vacuum distillation and hydrotreating are all sensitive operations. Adjustments in process conditions must be made slowly and in small increments to assure continuous specification performance. Considering this, the Extraction/Acid/Clay, Distillation/Clay and Distillation/Hydrotreating processes all operate at the highest on-stream efficiency 24 hours a day, seven days a week. If operated on a five-day week, some time (in addition to the two off days) would be lost in starting up, arriving at steady on-specification operating conditions, and in shutting down. Hence, the derated capacity of a five-day week would be something less than the ratio of 5 to 7.

Because the Acid/Clay process is a series of batch operations, it can be started up and shut down with little effect on efficiency. Thus there is a distinct advantage to the Acid/Clay process if the plant has to run at very low capacities, since it could easily turn down to a five-day week or even to less than 24-hour days and still maintain capacity essentially proportional to on-stream time.



TABLE 1.6
COMPARISON OF RE-REFINING ALTERNATIVES

	<u>Acid/Clay</u>	<u>Extraction Acid/Clay</u>	<u>Distillation/ Clay</u>	<u>Distillation/ Hydrotreating</u>
1. Lube yield	lowest	highest	medium	medium
2. Bright stocks	recovered	recovered	lost	lost
3. Utilities	lowest	highest	low	high
4. Overall energy	highest	high	lowest	medium
5. Hazardous chemicals	sulfuric acid	sulfuric acid	caustic	caustic
<u>Waste Streams</u>				
6. Acid sludge	most	some	none	none
7. Oily clay	most	some	some	none
8. Caustic sludge	none	none	some	some
9. Process water	lowest	low	medium	highest

Disc

NOTES

Item Number

1. Lube yield. The yield of lube oil in the Acid/Clay process is the lowest because of losses to the acid sludge. The two distillation processes do not recover bright stocks, and this is reflected in their medium lube oil recovery. By recovering bright stocks and reducing acid sludge losses (compared to Acid/Clay), the Extraction/Acid/Clay process shows the highest yield of lube oil (see also table in Section 1.4.2).
2. Bright stocks. The table shows that bright stocks are recovered only in the Acid/Clay and Extraction/Acid/Clay processes. These two processes would be favored in the unusual situation where waste lubes contained extremely high proportions of bright stocks.
3. Utilities. Total external energy (power plus fuel) is lowest for the Acid/Clay process and highest for the Extraction/Acid/Clay process (see Table 1.5).
4. Overall energy. This is line 11 plus line 14 in Table 1.5 which is the total of external energy (utilities) plus potential energy lost in non-recovered lube oils.
5. Hazardous chemicals. In the Acid/Clay and Extraction/Acid/Clay processes, the operators are exposed to the risk of handling sulfuric acid and the resulting acid sludge. In the two distillation processes, the operators are exposed to caustic and caustic sludge. All four processes expose the operators to possible chemical burns. The Acid/Clay process has the largest quantity of acid and sludge to handle, but the extra danger is



TABLE 1.6
(continued)

NOTES

Item Number

- marginal--careless operation or equipment failure with a small amount of acid can be just as serious as with a large amount.
6. Acid sludge. Acid sludge generated from the acid treating. See table in Section 1.9 for amounts.
 7. Oily clay. Oily clay removed from filters. This material is not hazardous except it may be hot (see table in section 1.9 for amounts).
 8. Caustic sludge. Caustic sludge generated in the naphtha-caustic centrifuging of the dehydrated lube oil in the two distillation processes (see table in Section 1.9 for amounts).
 9. Process water. Water generated in the treating sections, not including surface runoff (see table in Section 1.9 for amounts).



1.15 Industrial Oil

The preceding Sections 1.3 through 1.14 dealt with re-refining waste lubricating oils collected from automotive gasoline and diesel engines. Used industrial oils are a second major source of feedstock for re-refining. Falling under this general heading are cutting oils, turbine oils, compressor oils, gear lubricants, insulating oils, rolling oils and hydraulic oils.

In order to specify the type of processing necessary to re-refine industrial oils, it is essential to compare this source of feedstock to waste automotive oils.

- Since the industrial operator will be more careful of the lubricating system of his \$200,000 machine than the average car owner of his engine, waste industrial oils usually contain fewer degradation products and less dirt than automotive crankcase oils.
- Waste industrial oils are segregated by type of service, reclaimed separately and returned to their original service; waste automotive oil is a mixture of all kinds and sources of oil.
- Substantially all of the additives remaining in the automotive waste lubes must be removed during re-refining in order that the "additive response" of the re-refined product will closely approximate that of virgin oil. In contrast, since industrial oils are returned to their original service, the retention of unused additives is not a cause for concern and may, in fact, be an advantage.
- Industrial oils are free of lead, thus, in general, industrial oil re-refining does not employ processes as severe and complex as described previously for automotive waste oils. In some cases recycling of industrial oils may be as simple as filtering out solid particles. This could be done at the point of use.

When industrial oils are re-refined commercially, the process frequently consists of removing water and light petroleum fractions boiling and



treating with clay at elevated temperatures followed by cooling and filtering. Figure 5 shows such a treating process. The industrial oil user segregates his oils by type of service. The used oils are collected by the re-refiner in tank truck or drum lots. The re-refiner processes the oils in batches (usually 400 gallon minimum). As shown in Figure 5, the oil is first pumped to a mixing tank where clay is added. The clay and oil mixture is then sent to a treater. The oil is circulated through a heater to boil off any water and light petroleum fractions and then heated to the temperature required for the clay treating. The oil and clay are then sent to the filter feed tank, thereby, freeing the treater to accept another batch. From the filter feed tank the oil is cooled, filtered, further cooled, filtered again and sent to the product tanks where it may be air blown if the product has to pass a dryness test. The second filter acts as a guard in case of clay leakage through the first filter. If additives are required in the re-refined oil they can be added after the final filter. The yield of re-refined oil in this process is usually about 90%. Approximate utility and chemical consumptions per imperial gallon of product (excludes drum cleaning) are:

- Fuel: 4,500 Btu
- Power: 0.15 KW
- Clay: 0.35 pounds

After treating the oil, re-refined oil is returned to the original owner, completing the closed cycle. Drums used for shipping waste oil are cleaned by the re-refiner before use in the returning of the re-refined oil.



1.16 Antifreeze

The most common antifreeze used in automobile engine cooling systems is a mixture of ethylene glycol and water. The proportions vary depending on the freeze protection desired: a 50-50 volume mixture has a freezing point of about -35° F. Antifreeze available to car owners usually contains additives to prevent frothing and rust formation.

As the antifreeze solution is used it may become so dirty with rust and other contaminants that it loses its effectiveness as an engine coolant. Then the car owners drain and discard the old solution, flush out the cooling system and add fresh water and glycol. This replacement can be done at service stations, or the car owner can do it at home using kits sold by the glycol manufacturers.

The main contaminants in used antifreeze are rust particles, organic acids and other degradation products, oil and dirt. Figure 6 shows a process which is designed to recover glycol from such mixtures. The process consists of neutralizing any free acid content, filtering out any dirt, rust or precipitated sludge, followed by a two stage distillation. The ethylene glycol is extracted by removing water and volatile oils in the first stage followed by a second stage that removes the less volatile contaminants. A preliminary study indicates that the energy requirement of this process is in the range of 25,000 Btu per Imperial gallon of glycol recovered, refer to Figure 6.

Since most drivers service their cooling system in anticipation of winter driving, much of the waste antifreeze is produced in the late



summer and early fall. The seasonal nature of this production is a problem which would have to be resolved in the design of a commercial plant. A decision to install a large storage capacity to average out the daily capacity of a small plant, or to install less storage capacity with a larger reclaiming plant which might operate only part of the year, would have to be made. In either case the seasonal nature of waste antifreeze availability could make either alternative uneconomical unless other uses could be found for the process equipment during periods when feedstock is unavailable. Collecting the volumes of waste antifreeze to make recycling worthwhile may be a problem since it is so easy for a service station or car owner to drain the old solution down a sewer or onto the ground. Service stations would probably cooperate if storage facilities were provided, but an educational program would be necessary to get the average car owner to save his drained antifreeze.

Recycling waste antifreeze seems to be technically feasible. However, no commercial units are known to be in operation. Should there be a continuing interest in this field, the next step would be to assess the potential market and at the same time perform some preliminary laboratory studies to identify the contaminants and verify the recovery process.



CHAPTER ONE

REFERENCES

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2. "Waste Oil Study"; Report to the Congress authorized by Section 104(m), Public Law 92-500; U.S. Environmental Protection Agency; April 1974.
3. "Waste Oil Recovery Practices, State of the Art"; prepared for the State of Maryland Environmental Services and the U.S. Environmental Protection Agency; December 1972.



2. RE-REFINING PRODUCT COST AND QUALITY

2.1 Introduction

This chapter is divided into two distinct segments. The first segment, consisting of Sections 2.2 to 2.5, focuses on the economic aspects of the re-refining process: Section 2.6 contains an assessment of the quality of commercially available re-refined oil produced using the re-refining processes under consideration within this study.

The first segment, dealing with the economics of re-refining, has three major objectives:

- To provide cost and profit analyses to individuals or firms who may wish to consider an investment in a re-refining process. The analysis provides estimates of costs and profits for each of the four major types of re-refining processes and assesses the risks and benefits of alternatives in the design and size of facilities. An analysis of the sensitivity of costs and profits to changes in the values of key operating parameters is also provided.
- To provide detailed economic analyses to individuals within the government. This information will be used to balance the "profit motive" with issues of national interest, such as environmental effects and use of scarce resources, in assessing the desirability of alternative methods for waste oil utilization.
- To provide a consistent methodology for use in assessing the economic feasibility of alternatives in design and operation of re-refining facilities.

The first segment of this chapter is divided into four sections:

- Methodology of Analysis

A number of alternative methodologies historically have been used in assessing the economic viability of potential investments. The methodology used within this study provides an "internal rate of return to the investors after tax."



- Major Input Data and Assumptions

Within this section the major fixed and variable cost components for the investment cases being considered are described. The description provides details of the assumptions and calculations used to develop the input data.

- Analysis of Base Cases and Major Variants

In order to reflect a range of processes and plant sizes, fifteen base cases were evaluated. Analyses of variants to these 15 base cases are also included. The variant cases consider changes in cost of waste oil feedstock, changes in price of re-refined base stocks, contingency increases in investment capital, decreases in capacity of operation, and variations in allowable depreciation rates.

- Ranking of Process Designs and Operation Variants

Based on the preceding analysis, processes are ranked according to expected return on investment considering variations in process design and operation.

The last portion of the economic evaluation considers blending of lubricant additives with the base product produced in the re-refining process under study. The objective here is to evaluate the impact on profitability of selling compounded lube oils to final users.

The last segment of this chapter is devoted to the assessment of the quality of base oils produced by waste oil re-refining. Samples of waste oil feedstocks and finished base oils were obtained from a number of existing re-refineries, reflecting the spectrum of technologies analyzed within this study. Standard physical and chemical tests were performed on each sample in order to evaluate product quality. A comparison is made between the quality of the re-refined oils and commercially available virgin base stocks.



2.2 Methodology of Assessment

The methodology used within this study utilizes a time-related discounted case flow analysis producing an internal rate of return after tax. The annual costs and revenues for the entire life of the project from the start of construction to termination were modeled for each investment case, including the appropriate depreciation and tax effects, taking into account the influence of time on the annual flow of funds. This process both provides the most accurate means for calculating the potential rate of return, and allows for simulation of the effect of variations in plant design and operation on the rate of return.

Although a number of methods are used to evaluate the desirability of a potential investment, each method falls into one of five categories. The five investment analysis schemes commonly used are indicated below:

1. The ratio of prospective average annual profit after depreciation to original investment is sometimes alleged to be the prospective rate of return on investment. Often this is referred to as the "original book" method.
2. The ratio of prospective average annual profit after depreciation to the average book value is also sometimes alleged to be the prospective rate of return on investment. Often this is referred to as the "average book" method. (In many instances, it gives a figure for rate of return that is double the figure given by the "original book" method.)
3. The figures for prospective profit after depreciation for each year are divided by the prospective book value figures for the start of the respective year. This division gives a series of ratios that are alleged to be a year-by-year prospective rate of return. Conceivably, these rates might be averaged to give an overall figure for rate of return.



4. The average annual operating costs, including a depreciation allowance, are divided by the number of units of production. This average cost per unit is compared to the average sale price to provide a percentage return figure. This method does not accurately account for the original capital investment and does not appropriately reflect the purpose of depreciation.
5. The internal rate of return after tax method used within this study is a year-by-year modeling of actual costs and revenues, including taxes and depreciation allowances. The rate of return is then calculated to be that at which funds could be invested at a financial institution and draw down yearly for a given period of time, leaving a zero balance at the end of the evaluation period. As an example, if one were to invest \$100 in a bank and withdraw \$30 at the end of each year, leaving a zero balance at the end of the fourth year, \$120 would have been collected (if the bank were providing a 7.4% annual interest rate). The simplified calculation for this example is provided in Table 2.1 on the following page.

Both depreciation allowances and income tax rates affect the profitability of potential investments. A simplified example using amounts similar to those used in the previous example is provided in Table 2.2. However, in this case effective depreciation and a tax rate are included in the analysis. In the example, it is assumed that the \$100 investment is made in machinery that will increase profits \$30 per year before taxes, and that there is an allowable depreciation rate of \$25 per year. The assumed tax rate is 50% on taxable income. As can be seen from the example in Table 2.2, the depreciation allowance shields the profits from taxes and thereby increases the amount of internal cash flow after tax. The investor then has the opportunity to reinvest his funds in a duplicate piece of machinery to make up for obsolescence or assumed wear or in some other enterprise which might provide a more attractive return on investment.



TABLE 2.1
SAMPLE OF DISCOUNTED CASH FLOW

- Given:
1. \$100 invested in a bank.
 2. Withdraw \$30 at the end of the first year, second year, third year and fourth year.
 3. No funds remaining at the end of the fourth year.

Find: The annual interest rate the bank was paying for investments.

Calculation:

Years	A	B Present Worth Factors at 5%	C Present Worth A x B	D Present Worth Factors at 10%	E Present Worth A x D
N=0	(\$100)	1.0000	\$(100.000)	1.0000	\$(100.000)
N=1	\$ 30	.9524	28.572	.9091	27.273
N=2	\$ 30	.9070	27.210	.8264	24.792
N=3	\$ 30	.8638	25.914	.7513	22.539
N=4	\$ 30	.8227	24.681	.6209	18.627
Net Profit	\$ 20		\$ 6.377		\$ (6.769)

$$\text{Rate of Interest} = 5\% + \frac{6.377}{6.377 + 6.799} (10\% - 5\%) = 7.4\%$$



TABLE 2.2

SAMPLE OF DISCOUNTED CASH FLOW WITH DEPRECIATION AND TAX EFFECT

- Given:
1. \$100 investment in machinery, with a four-year life and no salvage value.
 2. Annual profits of \$30.
 3. Depreciation is \$25/year.
 4. Tax rate is 50 percent of profits.

Find: The "Internal Rate of Return After Tax."

Calculation:

Year	A	B	C	D	E	F	G	H	I
	Cash Flow	Depreciation Allowance	Taxable Income	Taxes $C \times 0.5$	Cash Flow After Tax $A - D$	Present Worth Factors at 2%	Present Worth $E \times F$	Present Worth Factors at 5%	Present Worth $F \times H$
N = 0	\$(100)				\$(100.00)	1.0000	\$(100.000)	1.0000	\$(100.000)
N = 1	30	\$25	\$5	\$2.50	27.50	.9804	26.961	.9524	26.191
N = 2	30	\$25	\$5	\$2.50	27.50	.9612	26.433	.9070	24.943
N = 3	30	\$25	\$5	\$2.50	27.50	.9423	25.913	.8638	23.755
N = 4	30	\$25	\$5	\$2.50	27.50	.9238	25.406	.8227	22.624
Net Profit	\$ 20				\$ 10.00		\$ 4.713		\$ (2.488)

$$\text{Internal Rate of Return After Tax} = 2\% + \frac{4.713}{4.713 + 2.488} (5\% - 2\%) = 3.96\%$$



The rate of return on an investment either in a bank, as in the first example, or in machinery, as in the second example, shows a value of 7.4% as compared to 3.96%. On a preliminary basis this indicates the investment in the bank is the preferred alternative. However, a 50% tax rate applied to the profits from the banking investment each year would make the internal rate of return after taxes nearly equal to that realized on the investment in machinery. Other factors would then be included in this example investment decision, such as "security and risk." It is quite certain that the rate of return from the bank is relatively reliable. In contrast, the profits from an investment in machinery could either be greater or less than anticipated in the evaluation.

2.3 Major Input Data and Assumptions

Within this section, the fixed and variable cost components for the four re-refinery cases are discussed. All calculations and assumptions are described to provide a complete understanding of the basis for each case to individuals contemplating investment, as well as to individuals within the government responsible for policy decisions.

The first phase of the economic analysis was a "screening process." Internal rate of return calculations were made for each of the technologies. The most promising combinations of capacity and technology were then reviewed in much greater detail in the second phase of economic analysis.



Based on preliminary calculations, the plant sizes utilized in the study were those assessed to be approximately at the "break-even points" of profitability. Initially, ten base cases were processed. Each of the ten cases had 27 separate inputs, or exogenous variables, as described in Table 2.3 on the following page. Cases 1 through 4 were based on the flow diagrams in Chapter 1. Each of these four cases requires 5.5 million gallons of waste lubricating oil feedstock in order to obtain the desired annual capacity of operation. Cases 5 through 8 represent smaller sized re-refining plants requiring approximately 3.5 million gallons of waste lubricating oil feedstock to maintain the desired annual capacity of operation. It will be noted that the payroll for Cases 1 through 8 remains the same. This is because the same size crew would be required for each case to maintain a 24-hour-a-day, seven-day-a-week operation. Two additional cases were run (Cases 9 and 10) assuming a reduced crew size for a five-day-a-week operation rather than a seven-day-a-week operation.

In Cases 1 through 8 it was assumed that the re-refinery operates at full capacity for 330 days each year. This allows approximately 35 days for shutdown and repair annually and represents an annual capacity factor of 90%. The 250-day-a-year operation assumes a plant utilization of five days a week, with ten days of shutdown time during normal operating time, in addition to weekends, for repairs. This represents an annual capacity factor of 68.5%. Both of these capacity factors are felt to be conservative, since most modern crude oil refineries historically have been available for operation with a capacity factor in excess of 95%.



TABLE 2.3

SUMMARY OF BASE CASE ASSUMPTIONS
FOR CASES 1 THROUGH 10

Item Number	Description	Case 1 Acid/Clay 330 Days/Year at 16,666 IGPD Feed	Case 2 Extraction/Acid/Clay 330 Days/Year at 16,666 IGPD Feed	Case 3 Distillation/Clay 330 Days/Year at 16,666 IGPD Feed	Case 4 Distillation/Hydrotreating 330 Days/Year at 16,666 IGPD Feed	Case 5 Acid/Clay 330 Days/Year at 10,527 IGPD Feed	Case 6 Extraction/Acid/Clay 330 Days/Year at 10,527 IGPD Feed	Case 7 Distillation/Clay 330 Days/Year at 10,527 IGPD Feed	Case 8 Distillation/Hydrotreating 330 Days/Year at 10,527 IGPD Feed	Case 9 Acid/Clay 250 Days/Year at 16,666 IGPD Feed	Case 10 Acid/Clay 250 Days/Year at 10,527 IGPD Feed	Item Number
1	Process plant	1,464	2,095	1,205	1,717	1,042	1,479	847	1,232	1,464	1,042	1
2	Offsites	700	1,039	668	745	564	815	539	539	700	564	2
3	Land and development	100	100	100	100	100	100	100	100	100	100	3
4	Administration during construction	200	200	200	200	200	200	200	200	200	200	4
5	Recruiting and training	116	145	145	145	116	145	145	145	86	86	5
6	Startup	78	109	98	101	79	105	97	100	58	58	6
7	Materials in process	225	240	225	225	142	151	142	142	225	142	7
8	Working capital	81	107	100	102	80	104	98	101	62	60	8
9	Waste oil costs (\$/Imperial gallons)	18	18	18	18	18	18	18	18	18	18	9
10	Annual waste oil feed (1,000 gallons)	5,500	5,500	5,500	5,500	3,474	3,474	3,474	3,474	4,167	2,632	10
11	Finished oil price (\$/Imperial gallon)	71	71	71	71	71	71	71	71	71	71	11
12	Annual finished oil sale (1,000 gallons)	3,960	4,579	4,180	4,180	2,495	2,885	2,633	2,633	3,000	1,892	12
13	Percent capacity--ratio to base	100	100	100	100	100	100	100	100	75.7	75.7	13
14	Power	6	20	6	8	4	13	4	5	5	3	14
15	Fuel and cutter	-	50	-	18	-	32	-	11	-	-	15
16	Water	2	6	2	3	1	4	1	2	1	1	16
17	Sulfuric acid	285	109	-	-	180	69	-	-	216	136	17
18	Clay	138	58	45	-	87	37	28	-	105	66	18
19	Propane	-	3	-	-	-	2	-	-	-	-	19
20	Waste disposal	160	41	4	-	-	26	-	-	-	-	20
21	Marketing costs	101	101	101	101	101	101	101	101	121	75	21
22	Payroll	425	520	520	520	425	520	520	520	364	364	22
23	High ash fuel revenues	-	35	92	92	-	22	58	58	-	-	23
24	Light fuel revenues	24	-	10	7	15	-	6	4	18	11	24
25	Percent depreciation rate	100	100	100	100	100	100	100	100	100	100	25
26	Percent of capital borrowed	70	70	70	70	70	70	70	70	70	70	26
27	Percent interest rate	12	12	12	12	12	12	12	12	12	12	27

NOTES, EXPLAINING COST FACTORS

Item Number of Computer Input (Exogenous)

- Process plant planned for startup in the fall of 1975. Installed cost of plant includes engineering and procurement fees. The plant cost for each process was determined by estimating the cost of each item of equipment shown on the Process Flow Diagram to produce a total cost of major equipment. This total was then multiplied by scaling factor to arrive at the installed plant cost. Individual equipment prices were obtained from "Modern Cost-Engineering Techniques" edited by Herbert Popper, and escalated to fall 1975 by using itemized "Refining Cost Indices" prepared by W. L. Nelson and published in the "Oil and Gas Journal". Two years of construction are assumed; therefore, the total plant costs are divided by two and put into each year of construction.

TABLE 2.3
(Continued)

NOTES EXPLAINING COST FACTORS
Item Number of Computer Input (Exogenous)

2. Installed cost of offsites includes buildings, tankage, boilers, electrical and simple loading racks. No blending, packaging or additive facilities are included. Costs are processed into construction years as in item 1.

3. Land and development costs cover price of land and fencing and assume a reasonably level building site. Cost estimate does not cover blasting, removal of underground obstructions or other unusual preparations. Costs are all assumed to be incurred in the first year of construction.

4. Administrative costs during construction. Assumes a two-year planning, engineering and construction period. Annual costs include:

Manager	\$ 35,000
Engineer	25,000
Secretary	10,000
Office rent	30,000
Total	\$100,000

5. Recruiting and training. Training of operators for a new plant varies with the complexity and size of the plant. The cost estimate includes two months of operating staff at the plant prior to startup for training, plus an allowance of one month's payroll for recruiting.

6. Startup costs include the initial plant operating period when production may be low due to operator inexperience, equipment problems, etc. Cost was taken as two months' payroll plus utilities (power, fuel and water).

7. Materials in process cover cost of waste oil feed and products in tankage and the process units. Basis for this cost is assuming feed and product tanks are half full.

8. Working capital assumes two months of payroll plus one month cost of utilities and supplies.

NOTE: The costs of items 4 through 8 vary considerably from refinery to refinery and are affected by site and size of the project, owners' capitalizing philosophy and preferences, complexity of the unit, assurance of feed and market, etc. The values used above are consistent with values used in preparing recent studies for major corporations, keeping in mind that this project is considerably smaller and less complex.

9. Waste oil cost at 18¢ per Imperial gallon, dry basis. See item 15 for basis.

10. Supply of waste oil assumed on a yearly basis.

11. Selling price of an Imperial gallon of lube oil base stock in Ontario, Canada.

a. Selling price of a U.S. gallon in Texas is 47¢.

b. Cost of water transportation is \$2 a barrel.

c. Import duty is 12.5% of item a.

d. Exchange rate of 1.03 Canadian dollar to 1.00 U.S. dollar.

[(0.47)(1.125)(42 gal(U.S.)/barrel) + \$2]1.02 = \$0.71

34.9735 gal. (Canadian)/barrel

Current review of prices paid by blenders of lubricating oil for the past several months (December 1975 and January 1976) in Ontario closely approximate this figure. The most current prices are slightly higher; therefore, 71¢ is a conservative estimate.

12. Annual production of finished oil sold.

13. Capacity as a ratio to the base case. The base case is assumed to be 330 days a year operation. Therefore, as an example, 250 days a year operation is 250/330 = 75.7% of the base case; or, on a yearly basis, represents a capacity factor of 250/365 = 68.5%.



TABLE 2.3
(continued)

NOTES EXPLAINING COST FACTORS
Item Number of Computer Input (Exogenous)

14. Cost of power was obtained from the Ministry of Treasury, Economics and Intergovernmental Affairs. For 12-60 kv the monthly cost is computed at \$3.46/kw demand plus energy at 7 mills per kwh (1976 basis).
15. Fuel and cutter stock. In this study all fuels, either purchased or sold, are related to the cost of the waste oil on a heating value basis. Waste oil (water-free) is set at 18¢ per Imperial gallon (\$6.30 per barrel)--typical for present prices in Ontario. This amount is equivalent to \$1.06 per million Btu. Fuel or oil purchased for cutter stock (as in the Extraction/Acid/Clay process) is priced the same as waste oil, or \$1.06 per million Btu. Natural gas used for feed and fuel in the Distillation/Hydrotreating process hydrogen plant was priced 25% higher, or \$1.33 per million Btu.
16. Water for process, boiler and cooling tower makeup was priced at a rate of 65¢/1,000 gallons for the first 100,000 gallons, plus 60¢/1,000 gallons for additional water (based on metropolitan Toronto monthly water rates for the Mississauga area).
17. 93% sulfuric acid at 6¢ per pound.
18. Clay at 7¢ per pound.
19. Propane makeup for solvent extraction at 3¢ per pound.

NOTE: The costs of items 17, 18 and 19 are based on 1973 values reported in Table 26 of "Waste Oil Study," Report to the Congress, U.S. Environmental Protection Agency, April 1974, and escalated to fall 1975.

20. Waste disposal. Neutralization and disposal costs, quoted from an Ontario operator, for acid sludge are 13¢/Imperial gallon. Clay disposal was quoted at \$10/ton.

21. Marketing costs. Assume:
Two salesmen @ \$22,500 \$ 45,000
Overhead, 90% of a. 40,000
Fringe benefits, 35% of a. 15,750
Total \$100,750

22. Payroll. Annual total for day workers plus shift workers. Day workers consist of:

Manager	\$ 35,000
Engineer	25,000
Accountant	20,000
Laboratory technician	20,000
Secretary	10,000
Day laborer	15,000
Total	\$125,000

Shift workers cover plant operations 24 hours per day, 365 days per year. Since each person works five shifts per week--less time off for sick leave, holidays and vacations--five persons are required to provide one man on a shift around the clock every day. Hourly rates include 25% for insurance and retirement and 10% for occasional unscheduled overtime.



TABLE 2.3
(continued)

NOTES EXPLAINING COST FACTORS
Item Number of Computer Input (Exogenous)

22. (continued)

	Persons Per Shift			Distillation/ Hydrotreating
	Acid/Clay	Extraction/ Acid/Clay	Distillation/ Clay	
Foreman @ \$10.50/hour	1	1	1	1
Category A operator @ \$9.25/hour	1	2	2	2
Category B operator @ \$9.00/hour	1	1	1	1
Total people per shift	3	4	4	4
Total persons	15	20	20	20
Annual shift payroll	\$300,000	\$395,000	\$395,000	\$395,000
Total annual payroll	\$425,000	\$520,000	\$520,000	\$520,000

23. High ash and light fuel revenues. The waste oil feed is assumed to contain 6.5% diluent material consisting of gasoline and diesel. These products are separated from the lube oil and burned in the plant as fuel. Any excess above plant fuel requirements appears as the by-product light fuel. Sale of this material is a credit to the process at waste oil cost, \$1.06 per million Btu. Light fuel is a product in the Acid/Clay, Distillation/Clay and Distillation/Hydrotreating processes. The Extraction/Acid/Clay process uses more fuel than is available in the feed diluent and so has no light fuel product (except in the high diluent feed alternate study).

In the Acid/Clay process the asphaltenes, polymers, metallic compounds and other heavy contaminants in the waste oil feed are rejected in the acid sludge and have no recovery value.

In the Extraction/Acid/Clay, Distillation/Clay and Distillation/Hydrotreating processes, the heavy materials are concentrated in the bottoms of the extraction tower or distillation tower and can be recovered as a high ash fuel. The heating value of these high ash fuels has been lowered to account for their noncombustible content. In addition, their sales price was reduced by 25% to 80¢ per million Btu to account for the nuisance these contaminants could be to the purchaser.

25. Depreciation. Note that a plant such as is being evaluated may be classified under Class 24 in which 100% of capital costs may be deducted the first year or a lesser amount deducted each of the first few years, as desired, if allowed by the Minister of Environment. The standard alternative allowed depreciation rate (under Class 8) is 20%, with a terminal loss of remaining balance at the end of operation, assuming no salvage value.

26. Percent of capital borrowed is 0.70 times items 1, 2 and 3.

27. Current assumed interest rate during construction and during length of loan if funds are borrowed. The project life is assumed to be ten years and the loan length is assumed to be the same.



The basis for the calculation of each of the figures provided in Table 2.3 may be found within the Notes Explaining Cost Factors at the bottom of the table. The first 27 figures represent exogenous inputs into the computer calculation; the effect on profitability of changes in one or more input variables can be readily determined by making additional computations.

Within the computer calculation there are several internal computations that may be thought of as endogenous input; interest during construction, inventory costs, transportation costs, maintenance and supplies, insurance, disposal of nondepreciated assets and taxes. These assumptions are listed in Table 2.4.

Annual costs for the following input variables are proportional to the operating capacity of the re-refinery:

Waste oil supply	Clay
Lube oil product	Propane
Power	Waste disposal
Fuel and cutter	Transportation
Water	High ash fuel
Sulfuric acid	Light fuel

The computer program calculates the proportionality for the above listed inputs. For example, 250 days a year operation as compared to the base case of 330 days a year operation represents an operational percentage of 75.8%. Therefore, each of the aforementioned costs is multiplied by 75.8% within the computer program to adjust the annual operation costs.



TABLE 2.4

SUMMARY OF INTERNAL COMPUTER PROGRAM ASSUMPTIONS

Please note that the following evaluation assumptions refer to calculations that are performed within the computer program.*

- Interest during construction. Assumes uniform delivery of equipment and/or services during the two-year construction period with interest at 12% per year.
- Inventory. Inventory covers supplies on hand for minor maintenance and upkeep, assumes 8% of maintenance and supplies, which in turn is 3% of computer input items 1 and 2 (process plant and offsites costs, respectively), refer to Table 2.3.
- Transportation of oil costs is calculated as follows: Total gallons of waste oil purchased divided by a tank truck capacity of 3,500 gallons, multiplied by \$50 a load. (Note: Some transportation costs are assumed in the cost of waste oil, and this amount represents a margin to insure costs are fully covered.) The transportation costs association with finished bulk oil is 10% less than the cost of transporting waste oil just described due to the loss in volume in the process.
- Maintenance and supplies were taken as 3% of the plant facilities and offsites (computer input items 1 and 2). This value is consistent with that used in several major oil company studies.
- Insurance was taken as 0.5% of computer input items 1, 2 and 3. This value is commonly used in economic studies but of course can vary by locality and depends on the complexity and layout of the plant.
- Nondepreciable asset costs are regained at the end of the project life as follows: sale of land, assuming no appreciation, and regain of working capital (computer input items 3 and 8).
- Taxes. The tax rate is assumed to be a composite 46% for both federal and provincial payments.

*Refer to Appendix 1 for details and copies of the computer runs.



Escalation or inflation rates have not been applied to either the annual operating costs or the annual average sale price of the finished lube oil product. This has been done for two reasons. First, it is not possible to forecast accurately the future rate of increase for both costs and prices. Second, a number of studies have escalated costs and prices using a single percentage rate. Such a process provides erroneously large future rates of return. Therefore, as a conservative assumption, the present differential between costs and prices is assumed to exist in the future for the base cases. Some of the variant cases do assume changes in the differential between current costs and prices. For these cases the internal rate of return after tax is significantly different than that calculated for the base cases.

The cost input assumptions utilized in this study were based on conservative estimates and adjusted, as necessary, as a result of discussions with refiners, blenders and re-refiners in Ontario. It is believed that with prudent management and close attention to financial operations, reductions in the cost of re-refining can be realized.

2.4 Base Case and Variant Cases: Calculations and Analysis

For each of the ten base cases described in Section 2.3, the after tax internal rate of return was calculated. The computer printout for each of these cases may be found in Appendix 1 to this Report.

The base case assumes that a major corporation would finance the costs during "construction" and "startup" out of "equity funds."



Equity funds, for example, would be profits from normal annual operations within a large corporation. Therefore, with equity funds there is no interest to be paid to the lenders, except that the corporation would require a minimum rate of return on invested capital, typically referred to as "opportunity cost" of capital. An alternative means of financing the capital costs would be to borrow a portion of the required capital from a lending institution. This means of financing will greatly affect the internal rate of return by means of "leverage." In this example, leverage means providing funds for a down payment and financing the remainder of the capital costs at some specified interest rate. In each of the following example cases, 70% of the capital costs (defined as the combined costs for process plant, offsites, and land and development) is financed at an annual rate of 12%. The period of the loan is assumed to be ten years. Both the percentage of capital borrowed and the interest rate assumed represent conditions existing in late 1975.

Tables 2.5 through 2.14 summarize the key input data and results of calculations based on the computer analysis found in Appendix 1, Volume 2. The leverage effect, which may be seen in Tables 2.5 through 2.14, occurs when the rate of return after tax differs from the assumed interest rate on borrowed funds. If the internal rate of return is much less than the rate of interest on borrowed funds, the net effect of an additional cost to pay the loan makes such a mode of operation less profitable than if equity funding had been used. The opposite effect of the leverage occurs when the internal rate of return after tax exceeds the interest rate on the capital funds borrowed.



TABLE 2.5

CASE 1

	Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
Acid/Clay Process; 330 Days/Year 16,666 Imp. Gal./Day	\$3,229	18¢	5,500	71¢	3,960	90%	\$792	66¢	4.4%
Borrowed 70% of Capital Cost	\$1,644	18¢	5,500	71¢	3,960	90%	\$134	69¢	1.6%
Variant 1 250 Days/Year Operation	\$3,229	18¢	4,166	71¢	3,000	68.5%	(\$696)	73¢	Not Profitable
Variant 2 23¢/Imp. Gal. Feedstock Cost	\$3,229	23¢	5,500	71¢	3,960	90%	(\$700)	73¢	Not Profitable
Variant 3 20% Higher Capital Costs	\$3,715	18¢	5,500	71¢	3,960	90%	\$448	68¢	2.1%
Variant 4 20% Depreciation Rate	\$3,229	18¢	5,500	71¢	3,960	90%	\$792	66¢	4.1%



TABLE 2.6

CASE 2

Extraction/Acid/Clay
Process; 330 Days/Year
16,666 Imp. Gal./DayBorrowed 70% of
Capital CostVariant 1
250 Days/Year OperationVariant 2
23¢/Imp. Gal. Feedstock
CostVariant 3
20% Higher Capital CostsVariant 4
20% Depreciation Rate

Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilization	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
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13.2%

22.2%

4.3%

7.8%
9.8%*10.0%
15.0%*11.8%
19.0%*

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.

TABLE 2.7

CASE 3

	Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilization	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
Distillation/Clay Process; 330 Days/Year 16,666 Imp. Gal./Day	\$2,970	18¢	5,500	71¢	4,180	90%	\$4,602	49¢	23.5%
Borrowed 70% of Capital Cost	\$1,589	18¢	5,500	71¢	4,180	90%	\$4,027	52¢	41.9%
Variant 1 250 Days/Year Operation	\$2,970	18¢	4,166	71¢	3,166	68.5%	\$2,149	57¢	12.2% 19.1%*
Variant 2 23¢/Imp. Gal. Feedstock Cost	\$2,970	23¢	5,500	71¢	4,180	90%	\$3,270	55¢	17.6% 30.3%*
Variant 3 20% Higher Capital Costs	\$3,391	18¢	5,500	71¢	4,180	90%	\$4,303	51¢	19.8% 35.5%*
Variant 4 20% Depreciation Rate	\$2,970	18¢	5,500	71¢	4,180	90%	\$4,602	49¢	20.8% 34.6%*

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.



TABLE 2.8

CASE 4

	Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilization	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
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Distillation/Hydrotreating
Process; 330 Days/Year
16,666 Imp. Gal./Day

\$3,636 18¢ 5,500 71¢ 4,180 90% \$4,264 51¢ 18.5%

Borrowed 70% of
Capital Cost

\$1,843 18¢ 5,500 71¢ 4,180 90% \$3,518 54¢ 33.3%

Variant 1
250 Days/Year Operation

\$3,636 18¢ 4,166 71¢ 3,166 68.5% \$1,779 59¢ 8.5%
11.2%*

Variant 2
23¢/Imp. Gal. Feedstock
Cost

\$3,636 23¢ 5,500 71¢ 4,180 90% \$2,900 57¢ 13.3%
22.0%*

Variant 3
20% Higher Capital Costs

\$4,189 18¢ 5,500 71¢ 4,180 90% \$3,872 52¢ 15.1%
26.3%*

Variant 4
20% Depreciation Rate

\$3,636 18¢ 5,500 71¢ 4,180 90% \$4,264 51¢ 16.4%
27.6%*

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.



TABLE 2.9

CASE 5

Acid/Clay Process;

330 Days/Year

10,527 Imp. Gal./Day

Borrowed 70% of

Capital Cost

Variant 1

250 Days/Year Operation

Variant 2

23¢/Imp. Gal. Feedstock

Cost

Variant 3

20% Higher Capital Costs

Variant 4

20% Depreciation Rate

Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
\$2,520	18¢	3,474	71¢	2,495	90%	(\$1,218)	76¢	Not Profitable
\$1,325	18¢	3,474	71¢	2,495	90%	(\$2,138)	80¢	Not Profitable
\$2,520	18¢	2,632	71¢	1,890	68.5%	(\$2,903)	86¢	Not Profitable
\$2,520	23¢	3,474	71¢	2,495	90%	(\$2,914)	83¢	Not Profitable
\$2,880	18¢	3,474	71¢	2,495	90%	(\$1,691)	78¢	Not Profitable
\$2,520	18¢	3,474	71¢	2,495	90%	(\$1,218)	76¢	Not Profitable



TABLE 2.10

CASE 6

	Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
Extraction/Acid/Clay Process; 330 Days/Year 10,527 Imp. Gal./Day	\$3,380	18¢	3,474	71¢	2,885	90%	\$ 520	66¢	2.7%
Borrowed 70% of Capital Cost	\$1,704	18¢	3,474	71¢	2,885	90%	(\$ 176)	70¢	Not Profitable
Variant 1 250 Days/Year Operation	\$3,380	18¢	2,632	71¢	2,186	68.5%	(\$1,347)	77¢	Not Profitable
Variant 2 23¢/Imp. Gal. Feedstock Cost	\$3,380	23¢	3,474	71¢	2,885	90%	(\$ 433)	72¢	Not Profitable
Variant 3 20% Higher Capital Costs	\$3,895	18¢	3,474	71¢	2,885	90%	\$ 155	68¢	0.7%
Variant 4 20% Depreciation Rate	\$3,380	18¢	3,474	71¢	2,885	90%	\$ 520	66¢	2.6%



TABLE 2.11

CASE 7

	Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
Distillation/Clay Process; 330 Days/Year 10,527 Imp. Gal./Day	\$2,338	18¢	3,474	71¢	2,633	90%	\$1,317	60¢	9.7%
Borrowed 70% of Capital Cost	\$1,297	18¢	3,474	71¢	2,633	90%	\$ 885	63¢	13.4%
Variant 1 250 Days/Year Operation	\$2,338	18¢	2,632	71¢	1,995	68.5%	(\$ 224)	71¢	Not Profitable
Variant 2 23¢/Imp. Gal. Feedstock Cost	\$2,338	23¢	3,474	71¢	2,633	90%	\$ 476	66%	3.7%
Variant 3 20% Higher Capital Costs	\$2,649	18¢	3,474	71¢	2,633	90%	\$1,097	61	7.3% 8.3%*
Variant 4 20% Depreciation Rate	\$2,338	18¢	3,474	71¢	2,633	90%	\$1,317	60¢	8.7% 11.6%*

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.



TABLE 2.12

CASE 8

Distillation/Hydrotreating
Process; 330 Days/Year
10,527 Imp. Gal./Day

Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
\$2,888	18¢	3,474	71¢	2,633	90%	\$1,013	62¢	6.2%
\$1,508	18¢	3,474	71¢	2,633	90%	\$ 440	66¢	5.9%
\$2,888	18¢	2,632	71¢	1,995	68.5%	(\$ 549)	74¢	Not Profitable
\$2,888	23¢	3,474	71¢	2,933	90%	\$ 152	68¢	0.9%
\$3,308	18¢	3,474	71¢	2,633	90%	\$ 715	64¢	3.8%
\$2,888	18¢	3,474	71¢	2,633	90%	\$1,013	62¢	5.7%



TABLE 2.13

CASE 9

	Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
Acid/Clay Process; 250 Days/Year 16,666 Imp. Gal./Day	\$3,160	18¢	4,167	71¢	3,000	90%	(\$ 269)	71¢	Not Profitable
Borrowed 70% of Capital Cost	\$1,575	18¢	4,167	71¢	3,000	90%	(\$1,262)	75¢	Not Profitable
Variant 1 250 Days/Year Operation									
			N O T	A P P L I C A B L E					
Variant 2 23¢/Imp. Gal. Feedstock Cost	\$3,160	23¢	4,167	71¢	3,000	90%	(\$2,075)	78¢	Not Profitable
Variant 3 20% Higher Capital Costs	\$3,646	18¢	4,167	71¢	3,000	90%	(\$ 679)	73¢	Not Profitable
Variant 4 20% Depreciation Rate	\$3,160	18¢	4,167	71¢	3,000	90%	(\$ 276)	71	Not Profitable



TABLE 2.14

CASE 10

Acid/Clay Process

250 Days/Year

10,527 Imp. Gal./Day

Borrowed 70% of

Capital Cost

Variant 1

250 Days/Year Operation

Variant 2

23¢/Imp. Gal. Feedstock

Cost

Variant 3

20% Higher Capital Costs

Variant 4

20% Depreciation Rate

Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
\$2,449	18¢	2,632	71¢	1,890	90%	(\$2,239)	83¢	Not Profitable
\$1,254	18¢	2,632	71¢	1,890	90%	(\$1,964)	88¢	Not Profitable
		N O T	A P P L I C A B L E					
\$2,449	23¢	2,632	71¢	1,890	90%	(\$3,524)	90¢	Not Profitable
\$2,809	18¢	2,632	71¢	1,890	90%	(\$2,712)	85¢	Not Profitable
\$2,449	18¢	2,632	71¢	1,890	90%	(\$2,239)	83¢	Not Profitable



The alternate to the base case, in which borrowed funds are utilized, will be of interest to individuals and firms who either lack the entire funds necessary for investment or wish to take advantage of the leverage effect.

In addition to the calculations of the base case utilizing either debt or equity funding, an analysis was made of the effect of variations in capacity utilization, feedstock cost, capital cost and rate of depreciation on the internal rate of return after tax.

The first variant assumes a decrease in capacity utilization from 330 days a year operation to 250 days a year operation. Operation for 330 days a year assumes that the plant is on-stream for 24 hours a day, seven days a week, with approximately 34 days "shutdown" time for maintenance and repairs.

The 250-day operation assumes that the plant is on-stream for 24 hours a day, five days a week, with ten working days in addition to weekends for maintenance and repairs. The reduced capacity is assumed to be unexpected, therefore the number of personnel required has not been reduced. Such an assumption simulates the actions of a re-refiner who does not want to let members of his crew leave should the business level increase. Alternate cases, discussed later in this chapter, do assess the effect of reduced crew sizes.

The second variant assumes an increase in the delivered cost of waste oil from 18¢ to 23¢ per Imperial gallon. Twenty-three cents per gallon approximates the price of residual fuel oil and represents an upper



bound to the cost of the competing fuels. In other words, an individual purchasing waste lubricating oil as a fuel would not be willing to pay more than the cost of residual fuel oil for burning purposes.*

Variant 3 assumes that the capital costs are 20% higher than estimated in the base case. While the base case capital investment costs were conservatively estimated, the purpose of this evaluation is to provide to the potential investor a measure of the risk should there be a fault in the estimates, an unexpected complication in construction, or a rise in the inflation rate during construction.

Under Canadian income tax law, the income from a business or property is the profit or net income after deducting the expenditures laid out to gain or produce the profit. The "expenditures" refer to "current costs," as well as to "depreciation." Under the Income Tax Act, a re-refinery may be classified in Class 24. Class 24 allows up to 100% rate of depreciation during the first year of operation, or a lesser amount should it be desired. Such a depreciation rate requires the approval of the Minister of Environment. At the other extreme, a re-refinery might be classified as Class 8. Class 8 allows a 20% depreciation allowance on capital costs each year. Both the 100% and 20% figures represent extremes. However, both of these percentages have been used in the evaluation to provide information to individuals within the government and industry with respect to potential policy decisions in the future that may affect re-refineries.

* This is a conservative assumption. On the basis of equivalent heating values the ceiling price for waste oil would be 19¢/gallon.



A ranking of base Cases 1 through 10, with their respective average costs of production and rates of return, is provided in Table 2.15. Base Case 3, the Distillation/Clay process, provides both the lowest cost per gallon of production and the highest rate of return after tax-- 49¢ per Imperial gallon and 23.5%, respectively. Case 3 was also five percentage points above its nearest competitor. Case 4, the Distillation/Hydrotreating process. Therefore, further analysis was performed for the Distillation/Clay process.

Most investors have a cutoff percentage rate of return below which no investment would be considered. This is sometimes represented as the "cost of capital" or an "investor's opportunity cost." Assuming this figure is currently 10%, Case 11 was developed utilizing all of the base assumptions within Case 3 but lowering the sale price of re-refined base oil to provide approximately a 10% internal rate of return after tax. The input assumptions for Case 11 are shown in Table 2.16. In a similar fashion, an increase of 5¢ per gallon above the base case sale price of 71¢ per Imperial gallon is represented in Case 12. A summary of the results of the computer calculation for both Cases 11 and 12 may be found in Table 2.17 and Table 2.18, respectively.

The results of Cases 3, 11 and 12 are displayed in Figure 2.1 entitled "Sensitivity Analysis of the Distillation/Clay Process, 330 Days a Year Operation at 16,666 Imperial Gallons per Day of Waste Oil Feed." The purpose for the development of the figure is to depict visually the sensitivity of the internal rate of return after tax to changes in the values of important independent variables.



TABLE 2.15

SUMMARY OF CASES 1 THROUGH 10

Base Cases	Process	Imperial Gallons Feedstock Per Day (IGPD)	Designed Operation and Equipment Sizing Rate (days/year)	Average Cost of Production ¢/Imperial Gallon	Assuming A Sale Price Per Imperial Gal. of 71¢, the Internal Rate of Return After Taxes	Ranking
Case 1	Acid/Clay	16,666	330	66¢	4.4%	6
Case 2	Extraction/Acid/Clay	16,666	330	56¢	13.2%	3
Case 3	Distillation/Clay	16,666	330	49¢	23.5%	1
Case 4	Distillation/Hydrotreating	16,666	330	51¢	18.5%	2
Case 5	Acid/Clay	10,527	330	76¢	NP*	8
Case 6	Extraction/Acid/Clay	10,527	330	66¢	2.7%	7
Case 7	Distillation/Clay	10,527	330	60¢	9.7%	4
Case 8	Distillation/Hydrotreating	10,527	330	62¢	6.2%	5
Case 9	Acid/Clay	16,666	250	71¢	NP*	9
Case 10	Acid/Clay	10,527	250	83¢	NP*	10

*NP - Not Profitable.



TABLE 2.16

SUMMARY OF ASSUMPTIONS FOR PRICING VARIANTS RELATED TO BASE CASE 3

Item Number	Description	Case 11	Case 12
		Distillation/Clay 330 Days/Year at 16,666 Imp. Gal./Day Feed	Distillation/Clay 330 Days/Year at 16,666 Imp. Gal./Day Feed
1	Process Plant	1,205	1,205
2	Offsites	668	668
3	Land and development	100	100
4	Administration during construction	200	200
5	Recruiting and training	145	145
6	Startup	98	98
7	Materials in process	225	225
8	Working capital	100	100
9	Waste oil costs (ϕ /Imperial gallon)	18	18
10	Annual waste oil feed (1,000 gallons)	5,500	5,500
11	Finished oil price (ϕ /Imperial gallon)	59	76
12	Annual finished oil sale (1,000 gallons)	4,180	4,180
13	Percent capacity--ratio to base	100	100
14	Power	6	6
15	Fuel and cutter	-	-
16	Water	2	2
17	Sulfuric acid	-	-
18	Clay	45	45
19	Propane	-	-
20	Waste disposal	4	4
21	Marketing costs	101	101
22	Payroll	520	520
23	High ash fuel revenues	92	92
24	Light fuel revenues	10	10
25	Percent depreciation rate	100	100
26	Percent of capital borrowed	70	70
27	Percent interest rate	12	12



TABLE 2.17

CASE 11

Distillation/Clay
Process; 330 Days/Year
16,666 Imp. Gal./Day

Borrowed 70% of
Capital Cost

Variant 1
250 Days/Year Operation

Variant 2
23¢/Imp. Gal. Feedstock
Cost

Variant 3
20% Higher Capital Costs

Variant 4
20% Depreciation Rate

Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
\$2,970	18¢	5,500	59¢	4,180	90%	\$1,893	49¢	10.9%
\$1,589	18¢	5,500	59¢	4,180	90%	\$1,319	52¢	16.2%
\$2,970	18¢	4,166	59¢	3,166	68.5%	\$ 97	57¢	0.6%
\$2,970	23¢	5,500	59¢	4,180	90%	\$ 561	55¢	3.4%
\$3,391	18¢	5,500	59¢	4,180	90%	\$1,595	51¢	8.2%
\$2,970	18¢	5,500	59¢	4,180	90%	\$1,893	49¢	9.8%

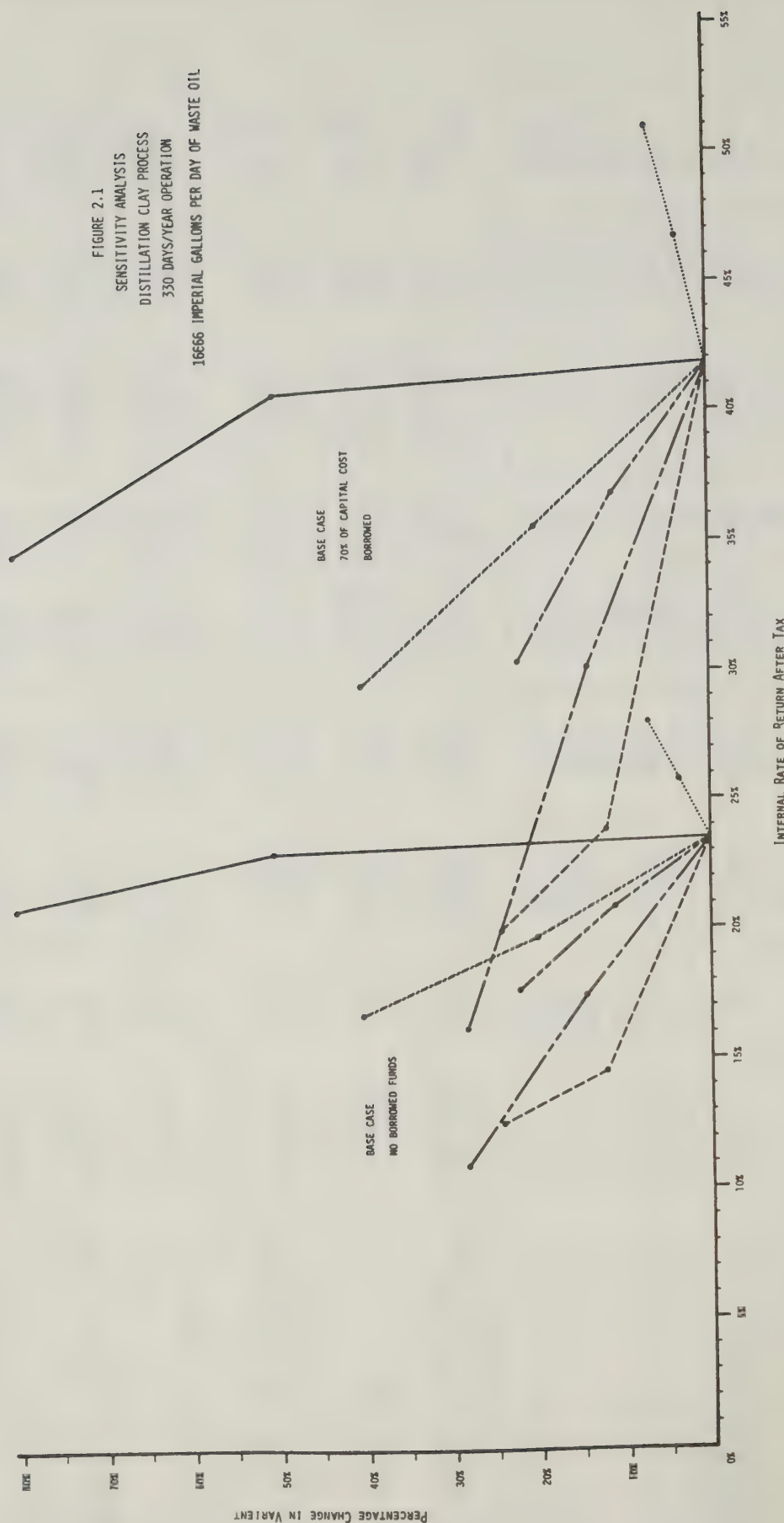


TABLE 2.18

CASE	12	Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
Distillation/Clay Process; 330 Days/Year 16,666 Imp. Gal./Day		\$2,970	18¢	5,500	76¢	4,180	90%	\$5,730	49¢	28%
Borrowed 70% of Capital Cost		\$1,589	18¢	5,500	76¢	4,180	90%	\$5,156	52¢	50.9%
Variant 1 250 Days/Year Operation		\$2,970	18¢	4,166	76¢	3,166	68.5%	\$3,004	57¢	16.4% 27.4%*
Variant 2 23¢/Imp. Gal. Feedstock Cost		\$2,970	23¢	5,500	76¢	4,180	90%	\$4,398	55¢	22.7% 40.1%*
Variant 3 20% Higher Capital Costs		\$3,391	18¢	5,500	76¢	4,180	90%	\$5,432	51¢	24.1% 44.1%*
Variant 4 20% Depreciation Rate		\$2,970	18¢	5,500	76¢	4,180	90%	\$5,730	49¢	24.8% 41.8%*

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.

FIGURE 2.1
SENSITIVITY ANALYSIS
DISTILLATION CLAY PROCESS
330 DAYS/YEAR OPERATION
16666 IMPERIAL GALLONS PER DAY OF WASTE OIL



- Change in days per year operation: Example -- $330-250/330 = 24\%$
- Change in cents per Imperial Gallon of waste oil feedstock: Example -- $23-18/18 = 22\%$
- Increase in "capital costs" as defined: 20% and 40% shown
- Change from 100% allowable rate of depreciation: Example -- $100-20/100 = 80\%$ and $100-50/100 = 50\%$
- Decrease in cents per Imperial Gallon of price finished base stock oil: Example -- $71-59/71 = 28\%$
- Increase in cents per Imperial Gallon of price finished base stock oil: Example -- $76-71/71 = 7\%$



The horizontal axis represents the internal rate of return after tax.

The vertical axis represents the percentage of change in an independent variable. The percentage changes in the independent variables analyzed are shown in the legend to the figure.

The family of lines on the left-hand side of the figure represent the base case with no borrowed funds. The family of lines at the right of the figure represent the base case, with 70% of the capital cost financed.

It may be seen in Figure 2.1 that the internal rate of return is least sensitive to changes in the depreciation allowance. The degree of sensitivity, or the slope of the line, is more pronounced in the borrowed capital case.

The internal rate of return after tax is very sensitive to changes in the annual operating capacity and the price charged for the re-refined product. It can be seen that the rate of change for both a reduction of 330 to 250 days per year of operation and an increase of 18¢ to 23¢ approximates the same effect as reducing the price of the finished lube oil product from 71¢ to 59¢ per Imperial gallon.

A note of caution is warranted with respect to the use of the sensitivity analysis. Intermediate points do not fall on the lines connecting the variant case results to the base case results. Therefore, extrapolations and interpolations cannot be made. Calculations or computer analysis,



such as performed within this study, are recommended should assessments of alternative assumptions be desired.

The Distillation/Clay process, operating at 330 days a year with 16,666 Imperial gallons of feed a day, has an attractive internal rate of return after tax even under unfavorable market conditions. However, a note of caution should be raised with regard to its potential development within Ontario. As a result of information developed by Teknekron during this study and as a result of preliminary assessments of the availability of waste oil products for recycling performed by the Ministry of Transportation and Communications, there is a concern about the availability of an adequate supply of waste oil feedstock.

In order to illustrate the difficulty of accounting for large quantities of waste lubricating oil potentially available for recycling, a "Simplified Flowsheet for the Lubricating Oil Cycle of Ontario" has been prepared (please see Figure 2.2 on the following page).

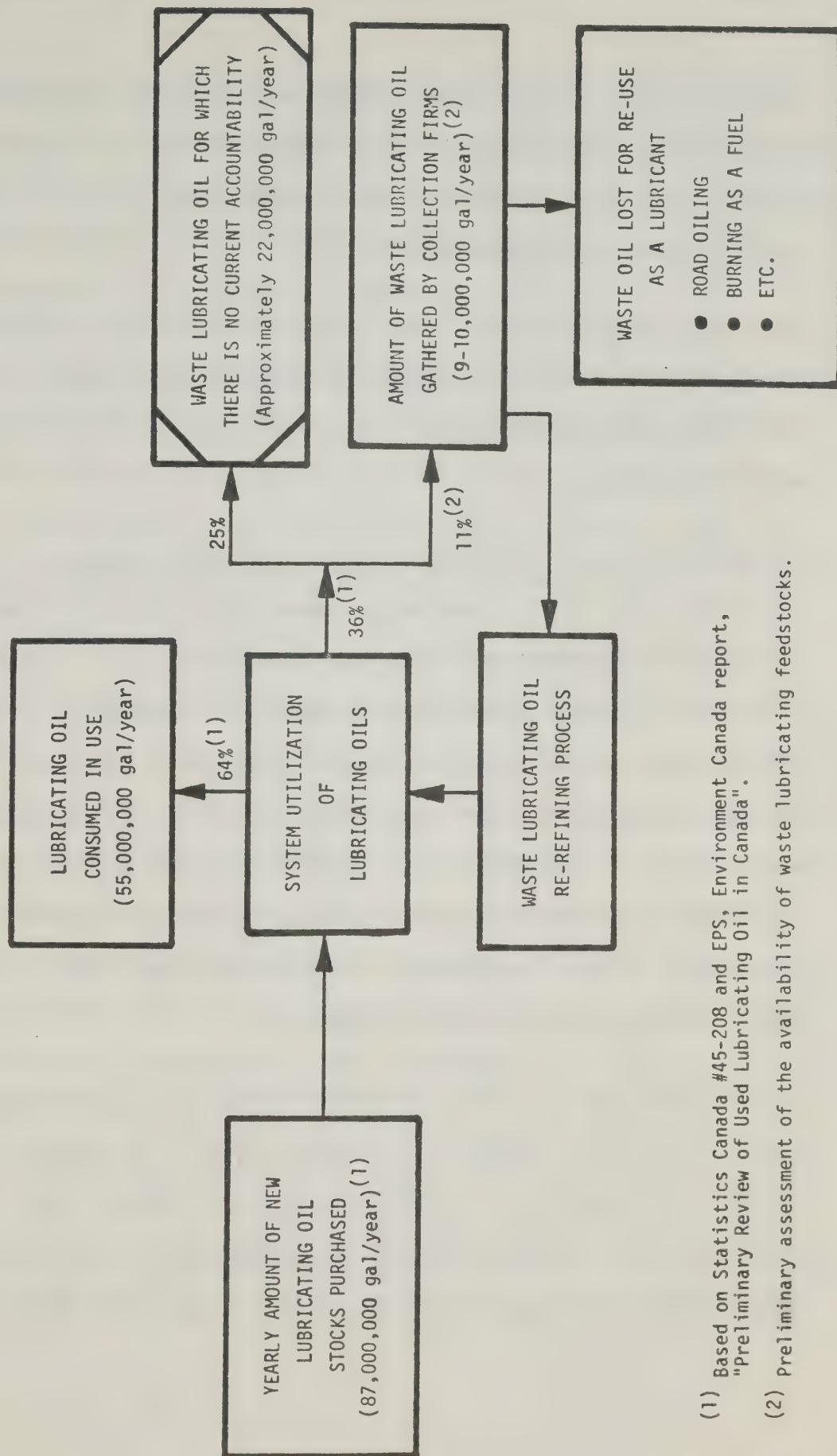
In a draft working paper on waste oil availability in Ontario, the Ministry has estimated that in 1973 approximately 87 million Imperial gallons a year of new lubricating oil stocks were consumed in the Province. This is indicated in the starting point of the diagram.

Information provided in the report, "Preliminary Review of Used Lubricating Oil in Canada," by Environment Canada, states that 64% (56 million gallons a year) of lubricating oils consumed in Canada is not available for further use. The remaining 36% (31 million gallons a year) is potentially available for recycle or reuse. These figures, while subject to debate, are the current assessment by Environment Canada.



FIGURE 2.2

SIMPLIFIED FLOW SHEET FOR THE LUBRICATING OIL CYCLE IN ONTARIO



(1) Based on Statistics Canada #45-208 and EPS, Environment Canada report, "Preliminary Review of Used Lubricating Oil in Canada".

(2) Preliminary assessment of the availability of waste lubricating feedstocks.



Based on a preliminary assessment of waste oil availability prepared by the Ministry of Transportation and Communications, of the 31 million gallons potentially available in Ontario each year, only 9 to 10 million gallons a year can be accounted for.

There are two major uses for waste lubricating oils which are collected. The first includes such utilization as road oiling, burning as a fuel, etc. The second use consists of utilizing waste lubricating oil in a re-refining process.

The capacity size of the Distillation/Clay process, reviewed in Cases 3, 11 and 12 in this study, requires an annual input of 5.5 million gallons of waste oil. Assuming that there were only 9 to 10 million gallons of waste oil gathered annually by the waste oil collectors, the re-refinery being considered would require in excess of 50% of all known available waste oil in order to maintain a desired scale of operation. Based on the limited amount of waste lubricating oil gathered by collection firms and the competing markets for waste oil other than re-refining, it would be extremely difficult to supply the required quantity of waste lubricating oil feedstock.

It should be noted that there are approximately 22 million gallons a year of waste lubricating oils for which there is no current accountability. If, however, this additional volume of waste oil did, in fact, exist and could be economically collected, then it is likely that the feedstock requirement of 5.5 million gallons a year could be obtained.



The limitations on waste oil availability in Ontario represent an important element of risk in an investment in re-refining. In order to avoid the risk of an inadequate supply of feedstock, a small scale re-refinery could be built. However, as shown in the analysis of cases 5-8, profitability falls sharply as plant size is decreased.

Each of the four technologies evaluated so far is designed to recover a high quality base oil from a wide range of contaminated lubricants. If a less sophisticated, lower-cost process could be employed, then the minimum economic size of the plant might be of such a scale that adequate feedstock availability could be reasonably assured.

In order to test this assumption, an economic analysis was made of an existing re-refinery located in Southern California. This firm employs a simple process in which used industrial oils are dehydrated in a clay slurry. Volatile hydrocarbons are then removed by steam stripping at elevated temperatures. The treated oil is cooled and filtered to remove the clay. This process is described in greater detail in Section 1.15 and Figure 5 of Chapter 1. Based on this simplified Dehydration/Clay process flow diagram, the process plant capital investment and operating costs were estimated. These are shown for two different size facilities (Cases 13 and 14) in Table 2.19. The summary of the computer calculation for Case 13 is presented in Table 2.20. This mode of operation is marginally profitable with an internal rate of return after tax of 4.9%. However, it should be noted that the existing plant represents a much greater profit to the owner



TABLE 2.19

SUMMARY OF BASE CASE ASSUMPTIONS
FOR CASES 13, 14 AND 15

Item Number	Description	Case 13			Case 14			Case 15		
		Dehydration/Clay 250 Days/Year 12 Hrs./Day Shift 4,000 Imp. Gals./Day Feed	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed, Closed Cycle Contracts Plus Profits From Blending	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed, Closed Cycle Contracts Plus Profits From Blending	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed, Closed Cycle Contracts Plus Profits From Blending	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed, Closed Cycle Contracts Plus Profits From Blending	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed, Closed Cycle Contracts Plus Profits From Blending	Dehydration/Clay 250 Days/Year 8,000 Imp. Gals./Day Feed, Closed Cycle Contracts Plus Profits From Blending
1	Process plant (1)	722	722	722	722	722	722	722	722	722
2	Offsites (2)	525	525	525	525	525	525	525	525	525
3	Land and development	100	100	100	100	100	100	100	100	100
4	Administration during construction	200	200	200	200	200	200	200	200	200
5	Recruiting and training	87	87	87	87	87	87	87	87	87
6	Startup	61	61	61	61	61	61	61	61	61
7	Materials in process	-	-	-	-	-	-	-	-	-
8	Working capital	62	62	62	62	62	62	62	62	62
9	Waste oil costs (¢/Imperial gallon) (3)	5	5	5	5	5	5	5	5	5
10	Annual waste oil feed (1,000 gallons)	1,000	1,000	1,000	2,000	2,000	2,000	2,000	2,000	2,000
11	Finished oil price (¢/Imperial gallon)	71	71	71	71	71	71	71	71	71
12	Annual finished oil sale (1,000 gallons) (4)	900	900	900	1,800	1,800	1,800	1,800	1,800	1,800
13	Percent capacity--ratio to base	100	100	100	100	100	100	100	100	100
14	Power	3	3	3	6	6	6	6	6	6
15	Fuel and cutter (5)	14	14	14	28	28	28	28	28	28
16	Water	1	1	1	2	2	2	2	2	2
17	Sulfuric acid	-	-	-	-	-	-	-	-	-
18	Clay	25	25	25	50	50	50	50	50	50
19	Propane	-	-	-	-	-	-	-	-	-
20	Waste disposal	4	4	4	8	8	8	8	8	8
21	Marketing costs	-	-	-	50 (6)	50 (6)	50 (6)	50 (6)	50 (6)	50 (6)
22	Payroll	172 (7)	172 (7)	172 (7)	414 (8)	414 (8)	414 (8)	414 (8)	414 (8)	414 (8)
23	High ash fuel revenues	-	-	-	-	-	-	-	-	-
24	Light fuel revenues	-	-	-	-	-	-	-	-	-
25	Percent depreciation rate	100	100	100	100	100	100	100	100	100
26	Percent of capital borrowed	70	70	70	70	70	70	70	70	70
27	Percent interest rate	12	12	12	12	12	12	12	12	12

TABLE 2.19
(continued)

Footnotes indicating revisions to assumptions described in Table 2.3:

- (1) Process plant cost includes capital costs required for blending additives with the base stock.
- (2) Includes costs of trucks, both tank and flatbed, and drums for collecting waste oil and distributing finished product.
- (3) Assumes payment to firms for collecting industrial waste oil of 5¢/Imperial gallon. This represents a difference from the assumption used in Cases 1 through 12 where 18¢/Imperial gallon was paid to waste oil collection firms delivering to the re-refinery.
- (4) Assumes a 90% yield from the feedstock collected from industrial firms based on assumed contractual arrangements. This compares to a 76% yield from crankcase waste feedstock assumed in Cases 1 through 12.
- (5) Cost of fuel and operation of the trucks used for collecting and delivering included.
- (6) Marketing costs were added to develop and maintain "close cycle contracts." Assumes one full-time man at 35% fringe benefits and 90% to cover overhead costs.
- (7) Assumes the nonunion wage scale paid by actual re-refiner interviewed.
- (8) Assumes the manpower requirements for 250 days a year operation found in Cases 11 and 12 plus \$50,000 to cover costs associated with one part-time and two full-time truck drivers.
- (9) Assumes the net increase in profit from blending additives is 6¢/Imperial gallon of finished lubricating oil. This figure represents an extremely conservative estimate; please refer to study text describing Case 15 for details.



TABLE 2.20

CASE 13

Dehydration/Clay Process
250 Days/Year
12 Hours/Day Shift
4,000 Imp. Gals./Day

Borrowed 70% of
Capital Cost

Variant 1
250 Days/Year Operation

Variant 2
23¢/Imp. Gal. Feedstock
Cost

Variant 3
20% Higher Capital Costs

Variant 4
20% Depreciation Rate

Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
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\$1,910 5¢ 1,000 71¢ 900 38% \$547 57¢ 4.9%

\$ 967 5¢ 1,000 71¢ 900 38% \$155 65¢ 3.0%

N O T A P P L I C A B L E

N O T A P P L I C A B L E

\$2,190 5¢ 1,000 71¢ 900 38% \$348 61¢ 2.7%

\$1,910 5¢ 1,000 71¢ 900 38% \$547 57¢ 4.6%



because the re-refinery was built in 1932. There is no current obligation to account for the original capital investment or depreciation. In effect, this re-refiner has only to account for annual operating costs of approximately \$286,000 in order to supply 900,000 Imperial gallons a year. The average cost, therefore, is approximately 32¢ per Imperial gallon of oil produced.

This re-refinery is markedly different from nearly all other existing firms. The company has nearly 150 industrial clients. No oil is sold to blenders. Each client's waste oil is custom re-refined in a separate batch operation. Thus a client's waste oil is never mixed with waste oils from other sources. Re-refined products are compounded to the customer's specifications. A single tariff is charged for waste oil collection, re-refining, compounding, and delivery of the re-refined product. An important limitation of this process is that only industrial oils, which are not highly compounded, can be properly re-refined. Used automotive crankcase oils cannot be recycled without more severe processing. This type of operation is frequently referred to as closed-cycle or custom re-refining.

Closed-cycle operations have a number of advantages over the more common open-cycle operation. First, the re-refiner has control over the supply of waste oil. Competition from road oilers or fuel marketers for feedstock supplies does not exist. Second, less sophisticated, lower cost technology can be employed for re-refining industrial oils than for re-refining automotive crankcase oils. In addition, since used industrial oils tend to be less contaminated than run-of-the-mill



crankcase drainings, the yield of re-refined product is substantially higher. Third, in closed-cycle operation, a finished (compounded) oil is produced for sale to a final user. The re-refiner can thus earn a profit on both the compounding and the re-refining operations. Finally, the competition in this type of market is provided by high quality finished oils marketed (and frequently produced) by major oil companies. Thus the closed-cycle re-refiner is somewhat protected from the rather wide fluctuations in the price of base oils which can occur in the wholesale market.

When operating in a closed-cycle mode, it is to the re-refiner's advantage to collect his own waste oil from the clients rather than to pay a collection firm. Specifically, a cost saving of about 12¢ per gallon of re-refined base oil is realized over the previous cases where waste oil was purchased from independent collectors at 18¢ per gallon.

Based on estimates of the availability of used industrial oils in Ontario, an additional case was run for the simple Dehydration/Clay process. The assumptions used in this analysis are shown in Table 2.19. The annual intake of waste oil feedstock was increased from 1 million to 2 million gallons a year, with a resultant product increase from 900,000 to 1,800,000 gallons a year. Marketing costs were added in order to establish and maintain contractual arrangements with industrial firms. The manpower estimates used in Cases 9 and 10, which assumed 250 days a year operation in Ontario, were utilized.



Additional labor costs to support drivers of collection vehicles were also added. Summary results for Case 14 may be found in Table 2.21. A marked increase in the profitability occurs due to the increase in capacity utilization; equity funding produces a 14.4% internal rate of return after tax; borrowed capital funds produce a 23.8% internal rate of return after tax. The corresponding average cost of production ranges from 52¢ to 56¢ per Imperial gallon. This mode of operation has further potential in that all profits have not yet been accounted for. Blending operations which are included in the estimates for capital and operating costs will substantially increase the rate of return after tax.

Typical blending charges in Ontario range from 6¢ an Imperial gallon of finished product for bulk supply to 20¢ an Imperial gallon for supply of ten drums or less. These prices are in addition to the actual delivered costs of the blending additives. An analysis of the prices of additives, the transportation costs, the volumes blended, the tariffs and the packaging costs may be found in Table 2.22 on the following pages.

Assuming a product mix of hydraulic, gear and cutting oils, the average markup on additives supplied in bulk quantities may be expected to be 50% based on blending prices previously quoted. The resultant prices for finished re-refined lubricants range from 9% to 28% less than the current market prices in Ontario for similar virgin products. Such a variance from the current market price might be used to insure that the desired sales volume was obtained. If this degree of discounting was



TABLE 2.21

CASE 14

Dehydration/Clay
Process; 250 Days/Year
8,000 Imp. Gals./DayBorrowed 70% of
Capital CostVariant 1
250 Days/Year OperationVariant 2
23¢/Imp. Gal. Feedstock
CostVariant 3
20% Higher Capital CostsVariant 4
20% Depreciation Rate

Total Initial Costs \$1,000	Waste Oil Cost ¢/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price ¢/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production ¢/Imperial Gallon	Internal Rate of Return After Tax
\$1,910	5¢	2,000	71¢	1,800	68.5%	\$1,729	52¢	14.4%
\$ 967	5¢	2,000	71¢	1,800	68.5%	\$1,337	56¢	23.8%
	N O T	A P P L I C A B L E						
	N O T	A P P L I C A B L E						
\$2,190	5¢	2,000	71¢	1,800	68.5%	\$1,530	54¢	11.5% 17.9%*
\$1,910	5¢	2,000	71¢	1,800	68.5%	\$1,729	52¢	12.9%

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.



TABLE 2.22

ANALYSIS OF TYPICAL BLENDING ADDITIVES TO BASE STOCK LUBRICANTS

The Hydraulic and Gear Oils:

Hydraulic Oil - "Rust and Oxidation" additive

-F.O.B. price 3.75¢/Imperial gallon

-Use 2% by volume; assumed are "oil" for shipment and tariff (Lubrizol 5142, example)

Hydraulic Oil - "Anti-Wear" additive

-F.O.B. Price 6.10¢/Imperial gallon

-Use 1% by volume; assumed are "chemical" for shipment and tariff (Lubrizol ANGLAMOL 75, example)

Gear Oil - Additive to meet U.S. Steel 224

-F.O.B. Price 6.4¢/Imperial gallon

-Use 3.5% by volume; assumed are "chemical" for shipment and tariff (Lubrizol 5002, example)

The Cutting Oils:

-F.O.B. price 6¢/Imperial gallon

-Use 4% by volume; assumed are "chemical" for shipment and tariff (Lubrizol 5311, example)

Tariffs:

-Lubricating oils composed wholly or in part of petroleum, not otherwise provided (n.o.p.) for under the most favored nation (m.f.n.) allowance for the U.S.A.

-Products of petroleum (chemical), n.o.p. for m.f.n.

(1/3¢/Imperial gallon)

Transportation:

-5¢/Imperial gallon for 200 miles

Drumming in Carload Lots:

-40¢/Imperial gallon

Pricing:

-6¢/Imperial gallon for blending plus the delivered cost of the additive in bulk quantities (1)

Calculations of Costs and Prices per Imperial Gallon (2)

-Hydraulic Oil - "Rust and Oxidation"

Additive Cost = $[(3.75)(.02)(1.125)] + [(.05 + .40)(.02)]$

= 9.3¢/Imperial gallon

Additive Price = $6.0 + 9.3 = 15.3¢$ /Imperial gallon

-Hydraulic Oil - "Anti-Wear"

Additive Cost = $[(6.10)(.01)] + [(.0033 + .40)(.01)]$

= 6.5¢/Imperial gallon

Additive Price = $6.0 + 6.5 = 12.5¢$ /Imperial gallon

-Gear Oil

Additive Cost = $[(6.40)(.035)] + [(.0033 + .40)(.035)]$

= 23.8¢/Imperial gallon

Additive Price = $6.0 + 23.8 = 29.8¢$ /Imperial gallon

TABLE 2.22
(continued)

Calculations of Costs and Prices per Imperial Gallon (continued) (2)

-Cutting Oil
Additive Cost = $[(6.00(.04)) + (.0033 \times .40)(.04)]$
= 25.6¢/Imperial gallon
Additive Price = $6.0 + 25.6 = 31.6¢/\text{Imperial gallon}$

	Percentage of Product Mix (3)	Costs	¢/Imperial gallon Average Factor	Price	Average Factor
Hydraulic Oil (R&O)	40%	9.3	3.72	15.3	6.12
Hydraulic Oil (A-W)	32%	6.5	2.08	12.5	4.00
Gear Oil	8%	23.8	1.90	29.8	2.38
Cutting Oil	20%	25.6	5.12	31.6	6.32
			12.82 average cost of additive in cents/ Imperial gallon		18.82 average price of additive in cents/ Imperial gallon

Average "markup" on additives $\frac{18.82 - 12.82}{12.82} = \frac{x}{100}$ x = 46.8%

Analysis of Foregoing Additive Prices to Current (Ontario) Market Prices (4)

-Hydraulic Oil - "Rust and Oxidation"
The current (early 1976) bulk price to the steel production and automotive manufacturing industries is approximately 95¢/Imperial gallon.

Adding the 15.3¢/Imperial gallon price for additives to the 71¢/Imperial gallon, used in the study for the assumed selling price of base stock lubrication oil, produces a selling price of 86.3¢/Imperial gallon which is about 9% less than the current market price.

-Hydraulic Oil - "Anti-Wear"

The current bulk price is approximately 1.05¢/Imperial gallon.

Adding 12.5¢/Imperial gallon for the additive price to the 71¢/Imperial gallon base stock price produces a selling price of 83.5¢/Imperial gallon which is about 20% less than the current market price.

-Gear Oil

The current bulk price is approximately 1.40¢/Imperial gallon.

Adding 29.8¢/Imperial gallon for the additive price to 71¢/Imperial gallon base stock price produces a selling price of 100.8¢/Imperial gallon which is 28% less than the current market price.

-Cutting Oil

The current bulk price is approximately 1.30¢/Imperial gallon. (5)

Adding 31.6¢/Imperial gallon for the additive price to the 71¢/Imperial gallon base stock price produces a selling price of 102.6¢/Imperial gallon which is about 21% less than the current market price.

(1) Typical blending prices in Ontario:

6¢/Imperial gallon - high-volume business, 200,000 gallons/year or a batch size of 10,000 gallons

10¢/Imperial gallon - batch sizes of 1,000 to 5,000 gallons

20¢/Imperial gallon - batch sizes of 10 drums or less



TABLE 2.22
(continued)

- (2) Cost savings are potentially available in purchasing additives separately rather than as a "package" of additives.
- (3) Assume: a typical industrial product mix based on high-volume uses in Ontario assessed from interviews with typical firms of 80% hydraulic and gear oils and 20% cutting oils. The hydraulic and gear oils are further broken down as 50% rust and oxidation oil, 40% anti-wear and 10% gear oils.
- (4) Based on interviews with blenders of lubricating oils in Ontario. No public documentation of current industrial lubrication products is available.
- (5) Prices for cutting oils will range up to about \$1.60 to \$1.80 per Imperial gallon for small quantities and/or specialized uses.



not found to be necessary, then higher profits could be realized from blending operations. Assuming that all sales are in bulk, the net increase in profitability of each finished Imperial gallon of product is 6¢. This increase in profitability was the only change in assumptions between Case 14 and Case 15 (see Table 2.19). A summary of the calculation results for Case 15 may be found in Table 2.23. Utilizing equity funding, the internal rate of return after tax is 18.5%; utilizing borrowed funds for the capital investment, this rate jumps to 32.3%.

2.5 Ranking of Processes and Design and Operation Variants

Based on the analysis in Section 2.4 and based on initial capital costs, efficiency of production and relatively low environmental costs, the Distillation/Clay process proves to be the most economically viable process.

The most attractive internal rate of return after tax stems from a mode of operation requiring 5.5 million gallons of waste oil feed each year. However, in view of the uncertainty that this volume of waste oil could be obtained, the smaller, less sophisticated Dehydration/Clay process may be a more viable opportunity for the re-refining of industrial oils which are not highly compounded. Automotive crankcase oils cannot be properly re-refined using the Dehydration/Clay technology. Further, this process cannot remove dirt, asphaltenes and gums except as they adhere to the clay or are filtered.



TABLE 2.23

CASE 15

Dehydration/Clay Process
250 Days/Year; 8,000 Imp.
Gals./Day Feed, Closed Cycle
Contracts Plus Profits
From Blending

\$1,910 5¢ 2,000 77¢ 1,800 68.5% \$2,312 52¢ 18.5%

Borrowed 70% of
Capital Cost

\$ 967 5¢ 2,000 77¢ 1,800 68.5% \$1,920 56¢ 32.3%

Variant 1
250 Days/Year Operation

N O T A P P L I C A B L E

Variant 2
23¢/Imp. Gal. Feedstock
Cost

N O T A P P L I C A B L E

Variant 3
20% Higher Capital Costs

\$2,190 5¢ 2,000 77¢ 1,800 68.5% \$2,113 54¢ 15.3%
26.1%*

Variant 4
20% Depreciation Rate

\$1,910 5¢ 2,000 77¢ 1,800 68.5% \$2,312 52¢ 16.5%
27.1%*

*This rate of return represents the rate of return if the borrowed case is better than the base case of equity funding.

Total Initial Costs \$1,000	Waste Oil Cost \$/Imperial Gallon	Annual Waste Oil Feed 1,000 Imperial Gallons	Finished Oil Price \$/Imperial Gallon	Annual Finished Oil Sales 1,000 Imperial Gallons	Percent Capacity Utilized	Total Cash Flow After Tax \$1,000	Average Cost of Production \$/Imperial Gallon	Internal Rate of Return After Tax
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In summary, re-refining in Ontario may prove to be economically viable. The critical uncertainties are the availability and quality of waste lubricating oil. This uncertainty should be carefully considered by firms contemplating investment in re-refining processes or by government officials following a policy of promoting re-refining within Ontario.

2.6 Re-refining Product Quality

2.6.1 Introduction

Samples of waste oil used in several different re-refining processes and corresponding samples of re-refined products were collected and analyzed in the laboratory. The results are presented in Table 2.24.

Five different Acid/Clay operations are represented (Samples 2, 3, 5, 6 and 7), but in the case of two of them (Samples 3 and 5), only the re-refined products were available. "Before and after" samples of a Distillation/Clay process (Sample 4) were obtained from one location. Another source made available the waste oil used and small amounts of the products from commercial scale Acid/Clay and laboratory scale Distillation/Hydrotreating processes (Sample 6). Still another operator supplied samples of the waste oil and product of a process which he preferred not to describe (Sample 1).

In addition, two samples of neutral oils (Samples 8 and 9) were obtained from different large-scale commercial refineries operating on natural crude oils. These samples are included for reference to show the quality of some virgin oils with which re-refined oils would compete. Other



Table 2.24

Physical and Chemical Properties of Lubricating Oil Samples

	ACID/CLAY PROCESSES						DISTILLATION/ HYDROTREATING		DISTILLATION/ CLAY		UNKNOWN PROCESS		REFINED NEUTRALS FROM VIRGIN CRUDES	
	2A		3A		5A		6A		4A		1A		88	
	Product	Waste Oil	Product	Waste Oil	Product	Waste Oil	Product	Waste Oil	Product	Waste Oil	Product	Waste Oil	Product	Waste Oil
Color	4.0	---	5.0	---	7.0	---	3.5	---	5.0	---	4.5	---	0.5	---
Gravity, API @ 60° F	30.1	24.8	30.2	27.0	29.3	28.5	29.8	30.2	27.5	24.1	28.7	24.9	30.2	30.6
Pour Point, °F	+10	-25	+5	-30	+10	+15	-5	+10	+5	0	+10	-25	-5	-5
Flash Point, °F	380	---	465	---	335	415	---	---	450	---	450	---	415	405
Viscosity, SUS @ 100° F	388	377	325	237	235	391	261	176.7	479	306	288	290	263	200
Viscosity, SUS @ 210° F	58.2	---	54.8	52.0	49.8	60.0	50.5	45.3	66.2	---	52.1	53.6	50.9	46.5
Viscosity Index	101	---	106	133	112	112	102	104	115	---	101	114	97	99
Total Acid Number	0.06	3.70	0.11	1.65	0.90	0.08	0.11	0.06	0.28	2.49	0.06	4.79	0.02	0
Total Base Number	0.03	2.18	0.03	2.32	0	0	0	0	0.22	2.60	0.03	2.24	0	0
Strong Acid Number	0.02	1.29	0	0.36	0.31	0.01	0.01	0.01	0.03	0.67	0.02	2.10	0	0
Sulfated Ash, %	<0.01	1.52	<0.01	0.95	0.02	0.01	<0.01	<0.01	0.02	1.06	0.02	1.90	<0.01	<0.01
Carbon Residue (RAM), %	0.52	2.05	0.42	1.73	0.41	0.57	0.26	0.13	0.32	1.55	0.44	3.11	0.25	0.26
Total Ash, %	0.128	1.33	0.007	0.89	0.003	0.013	<0.01	0.006	0.015	0.98	0.021	1.73	0.011	<0.001
Benzene Insolubles, Uncoag., %	<0.01	0.21	<0.01	0.25	<0.01	<0.01	<0.01	<0.01	<0.01	0.15	<0.01	0.45	<0.01	<0.01
Copper Corrosion	2	4	1	1	4	1	2	1	2	2	2	4	1	1
Sulfur, %	0.011	0.48	0.017	0.06	0.017	0.047	0.22	0.10	0.018	0.40	0.21	0.54	0.010	0.06
85 % W, %	---	3.0	---	4.0	---	4.0	---	---	---	5.0	---	3.0	---	---
Crankcase Dilution, %	---	>10	---	>10	---	>10	---	>10	---	>10	---	>10	---	---
SPECTROGRAPHIC ANALYSIS, PPM														
Iron	<1	280	5	175	10	<1	<1	<1	1	240	<1	410	<1	<1
Lead	<5	>500	<5	>500	<5	<5	<5	<5	<5	>500	<5	>500	<5	<5
Copper	<1	46	<1	45	<1	<1	<1	<1	<1	24	<1	34	<1	<1
Chromium	<1	13	<1	1	<1	<1	<1	<1	<1	20	<1	9	<1	<1
Aluminum	<1	23	<1	18	7	<1	<1	<1	<1	15	<1	18	<1	<1
Nickel	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silver	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Silicon	<1	14	<1	13	<1	<1	<1	<1	<1	11	<1	8	<1	<1
Boron	<1	23	<1	11	<1	<1	<1	<1	<1	18	<1	26	<1	<1
Sodium	<1	240	<1	900	<1	<1	<1	<1	5	500	<1	150	<1	<1
Phosphorus	<100	1100	<100	600	<100	<100	400	<100	<100	550	<100	1000	<100	<100
Zinc	<100	1000	<100	700	<100	<100	<100	<100	<100	650	<100	1300	<100	<100
Calcium	<100	1500	<100	1000	<100	<100	<100	<100	<100	1400	<100	1400	400	<100
Barium	<500	600	<500	500	<500	<500	<500	<500	<500	500	<500	500	<500	<500
Magnesium	<1	450	<1	180	9	<1	<1	<1	<1	240	<1	650	<1	<1

> = Greater Than < = Less Than



virgin oils may have properties different from these, but would be equally free of fuel and metallic and acidic contaminants.

2.6.2 Summary

The quality of the re-refined oils is significantly better than that of the waste oils. The best two (and fairly comparable) samples of re-refined oil are an Acid/Clay product (sample 7A) and the Distillation/Hydrotreating product (sample 6B). The worst is from an Acid/Clay operation (sample 5A).

The results emphasize the need to consider a number of criteria in judging a given re-refining operation or in comparing re-refining processes. These criteria include the quality of waste oil used, the kind and condition of equipment used, and the skill and care with which the process is operated.

Waste oil samples 6B and 7C appear to be used motor oils (although more lightly compounded than current SE oils). Because of the more uniform nature of motor oils and the additives used in them (compared with a mixture of industrial oils), segregation of waste crank-case oils is not critical to producing a quality re-refined product. Therefore, if the process is well controlled, a reasonably high quality product should result. Indeed, that did happen in the case of samples 7A and 6B, with the products approaching the quality of the reference virgin oils. With improvement in the operations, it is quite conceivable that the quality of these re-refined oils could match that of the virgin oil products.



On the other hand, the firm which supplied sample 5A utilizes a waste oil composed of a mixture of industrial oils. This feedstock is probably composed of oils having widely different characteristics, mainly as a result of the additives used. Although a sample of the waste oil was not available, it is clear that such a feedstock would be difficult to re-refine, especially if the operation were not well controlled.

The objectives of re-refining operations are important in considering the effectiveness of various processes. For example, a well run Acid/Clay operation can receive waste oil from a large customer, process it separately from other oils, blend the re-refined product with appropriate additives and return the oil for re-use in the client's equipment. Indeed, this has been done with diesel engine oil for a number of railroads for many years. However, such an operation would have to be supplemented with distillation equipment if the objective were to offer a line of oils suitable for oil product blenders. Virgin oil refineries produce a number of neutral oils, differing in viscosity, for their own use in blending various oil products, and for sale to other blenders. This is necessary to achieve the viscosity desired in the final product. A given refinery may produce a 100 neutral, a 250 neutral, and a 500 neutral oil, for example. (The numbers refer to the Saybolt viscosity at 100 degrees F.) Neutral oils are the overhead products of the distillation process.

In considering the laboratory data to determine how suitable the oil is for further use, the following criteria have been taken into account:



- a. Removal of fuel contaminants. Efficiency of the contaminant removal can be judged by testing the flash point, viscosity, carbon residue, and lead content of the re-refined oil.
- b. Removal of metal contaminants from wear, corrosion and dust. The presence of metal contaminants is tested by analysis for iron, copper, lead, silicon and sulfated and/or total ash.
- c. Removal of acidic contaminants from fuel and oil oxidation, and removal of additive residues. Removal of acids and additive residues is monitored by determining the total acid number, total base number, strong acid number and sulfated ash content of the re-refined oil.

The number of samples obtained is suitable for indicating trends. A larger number would be required to demonstrate specific trends, such as would be required for a definitive comparison of the quality of oils produced using different re-refining processes. The test results obtained on these samples are considered reasonably reliable. In considering the results, however, repeatability in the same laboratory and reproducibility between laboratories must be taken into account. For example, the American Society for Testing Materials (ASTM) has established that repeatability of a test which yields a strong acid number in the range of 0.05-1.0 is 0.02, and that the reproducibility of this test is 0.04. Thus, a strong acid number of 0.02 can, for practical purposes, be considered to be zero. Specific lubricating oil tests and their significance are discussed in Section 2.6.3, below.

Finally, a number of industry standards for hydraulic oil and lubricating oil require performance tests. These tests are necessary because the results of physical and chemical laboratory tests, such as those presented in this report, are not sufficient to show that



the performance of even virgin oils compounded with suitable additive packages will be satisfactory. Therefore, it must be understood that the evaluation of the oils considered here only shows whether they may be satisfactory base oils for further additive blending. The additive response of these oils, that is, the performance of the oil to a given amount of a given additive is not known. Thus, Oil A plus 8 percent of Additive X may pass a given performance test. But Oil B may require 9 percent or more of Additive X to perform equally well.

2.6.3 Lubricating Oil Tests and Their Significance

This section provides a brief description of the laboratory tests of physical and chemical properties of lubricating oils, and the significance of these tests in assessing the quality of re-refined products.

Gravity. The general source of crude oil is indicated by its gravity: crudes from the U.S. Gulf Coast are low in gravity number, those from the Mid-Continent area are medium, and those from Pennsylvania are high in gravity number. Oil products have the following characteristic gravity number ranges: gasoline, 50-60; kerosene, 30-40; lubricating oils, 20-30. Comparative values before and after treatment of waste oil indicate the degree of removal of sludges (heavy molecules) and fuel dilution (lighter molecules).

Color. This is a general indication of the degree of treatment, but not necessarily a measure of product quality. A rating of 0 applies to a transparent oil with only a trace of straw color. A rating of 8 is black and opaque. A maximum rating of 5 is considered acceptable.



Pour Point. This property is an indication of the lowest temperature at which a given product can be used. It is also a rough indicator of the crude source of the oil product; however, the presence of pour point suppressants would mask any crude source indication. The test suggests the degree of removal of diluents from the waste oil in re-refining operations.

Flash. Flash point is used as a refinery control test, and is useful in re-refining operations as a measure of the removal of fuel diluents from the waste oil.

Viscosity. This is a fundamental criterion of the suitability of a lubricating oil for its intended use. Viscosity measurement is also used to classify oils into several viscosity ranges for application in suitable ambient temperature ranges. Fuel dilution of engine oils lowers the viscosity. Therefore, viscosity can be used as a measure of the removal of diluents from waste oil in re-refining processes.

Viscosity Index (VI). In the case of virgin oils, the VI is an indication of the crude oil source. Coastal crude lubes are usually in the range of 30-35 VI, while those from Mid-Continent and Pennsylvania crudes are usually 90-100 VI. As most quality motor oil base stocks today are in the 90-100 range, re-refined oils should fall into the same bracket. Viscosity index is an important measure of the suitability of an oil for service where wide variations in temperature are encountered. Thus, premium motor oils have viscosity indices in the range of about 130-140. Such high indices are achieved by the use of VI improvers in the blending operation.



Total Acid Number (TAN). This is a measure of the degree of oxidation of the base oil, as well as an indicator of the amount of additives in compounded oils. To be acceptable, the TAN of re-refined oils should be less than 0.10.

Total Base Number (TBN). The additive compounding level in crankcase oils is indicated by the TBN. This test can be used to determine the degree of additive removal in re-refined oils. To be acceptable, the TBN of a re-refined product should be less than 0.06.

Strong Acid Number (SAN). This is a measure of acids present which may corrode engine bearing metals. The SAN of re-refined base oils should be less than 0.04.

Sulfated Ash. Of interest principally in crankcase oils, this is a measure of the additives present in both new and used lubricants. The sulfated ash content of a re-refined base oil should be less than 0.02 percent.

Total Ash. In general, the results are used for the same purpose as are those from sulfated ash measurements.

Carbon Residue. In new or refined oils, this is a measure of carbon forming tendencies when the oil is exposed to coking conditions. It reflects the crude oil source and type as well. In waste oils, the measurement will include carbonaceous material formed during prior use. In re-refined oil products, the test serves as an indication of how well contaminating carbonaceous materials (asphaltenes from



oxidation, fuel dilution, etc.) have been removed. The carbon residue of a re-refined oil should be less than 0.5 percent.

Benzene Insoluble, Uncoagulated. This is a measure of particulate contaminants, such as dust and metallic particles. A level of less than 0.01 percent is acceptable.

Copper Corrosion. The corrosive tendencies of acids formed during oxidation, or added in the form of additive compounds, are indicated by this measurement. In the case of re-refined oils, the degree of removal of acid used in the process is indicated. The higher the rating, the more corrosive is the oil. A level of 2 or less is acceptable.

Sulfur. This is a measure of residual sulfur as well as the sulfur added with the compounding additives. Appraisal of its harmful effects must consider other tests, such as copper corrosion. The sulfur content should be less than 0.2 percent.

Bottom Sediment and Water (BS&W). The amount of sludge and water in used oil is measured in this test. It is an indication of the amount of those contaminants which must be removed in the re-refining process.

Crankcase Dilution. This is a measure of the dilution of crankcase oil with unburned fuel which must be removed in re-refining.

Spectrographic Analysis. This procedure determines the concentrations of certain metals in oils. The types and amounts of certain additives present (barium sulfonates, calcium sulfonates, zinc dithiophosphates, etc.)



in oils are indicated by barium, calcium, zinc and phosphorus levels. The severity of wear and/or corrosion of piston rings, bearings, etc., can be judged by the amounts of iron, copper, lead and aluminum present. To be considered fit for further use, the metal content of a re-refined oil should be markedly lower than that of the waste oil from which it was produced.

2.6.4 Discussion of Test Results

2.6.4.1 Reference Oils

These virgin products are 200 neutral and 250 neutral lubricating oils typical of large scale crude oil refining operations. The oils are characterized by very light color, chemical neutrality, very low ash and sulfur levels and by the virtual absence of metals. Their viscosity indices, as well as their carbon residues, indicate that they probably originated from similar crude sources. Carbon residues of virgin oils vary with regard to the hydrocarbon composition of the crude source.

2.6.4.2 Acid/Clay Process

The test results on samples 2A, 3A, 6A and 7A indicate that the Acid/Clay process can be quite effective in removing contaminants from waste oils. An exception is sample 5A for which the total acid number far exceeded permissible limits. (Although a corresponding waste oil sample was not available, it is likely that little clean-up was achieved.)



A comparison of tests on samples 7A and 7B indicates that the re-refined product (7A) is acceptable in almost all respects. The flash point, viscosity and reduction in lead indicate that the fuel dilution has been substantially removed. The low sulfated ash, the reduction in calcium, barium, zinc and phosphorous indicate that virtually all the additives have been removed. The oil is also quite free of air-borne contaminants such as silicon and of engine wear and corrosion metals such as iron, lead, copper and aluminum. The low values for total and strong acid numbers, and the zero total base number indicate the satisfactory removal of all corrosive contaminants.

A comparison of tests on samples 6A and 6C indicate that the re-refined product (6A) is not entirely free of contaminants. Fuel dilution, judging from the changes in pour point, viscosity, and carbon residue are acceptable. The significant reduction in total ash indicates that the oil is very clean. However, the total acid number and the sulfur level are too high to be satisfactory.

With regard to fuel dilution and cleanliness, re-refined sample 3A appears to be satisfactory. However, the slightly high total acid number indicates the need for further treatment.

The quality of re-refined oil sample 2A was improved significantly over that of waste oil sample 2B. The very low sulfated ash indicates that the additives have been substantially removed. However, the total acid number is marginally high, and the total ash is too high. Slightly more severe treatment of the waste oil would likely result in a better color, a lower ash content and a more neutral product.



2.6.4.3 Distillation/Hydrotreating Process

For this process, only one re-refined oil, sample 6B, could be obtained. This sample exhibits very good quality. It is quite clean (very low carbon residue and total ash), and has been reasonably well neutralized. Although the sample was too small to permit flash point measurement, the improvement in pour point indicates good removal of fuel contaminants. The viscosity is not much higher than the waste oil, but that may be because the sample is a light cut off the distillation column and not representative of the whole oil. An improvement could be made in the sulfur level. This type of process has the potential of producing very satisfactory products

2.6.4.4 Distillation/Clay Process

Re-refined sample 4A is reasonably free of contaminants found in the waste oil sample 4B. The high flash point and increase in viscosity indicate fairly complete removal of fuel dilution. The improvements in total ash and carbon residue show that the oil is quite clean. Further, the significant reduction in sulfated ash means reasonably complete removal of additives. However, the high total base and total acid numbers indicate incomplete removal of soluble acids. A heavier clay treatment would probably correct this deficiency.

2.6.4.5 Unknown Process

As evidenced by the satisfactory values for flash points, pour point and carbon residue, fuel dilution seems to have been well removed from re-refined sample 1A. However, the viscosities are not consistent with that conclusion. Tests for carbon residue and total ash indicate



that the oil is reasonably clean. The low sulfated ash number indicates nearly complete removal of additives. The total acid number and the sulfur content are slightly high.

2.6.5 Summary

The analyses of these samples indicate that the re-refining processes represented are capable of producing oils suitable for further use. Good control of any process is necessary to produce acceptable oils and to do so consistently. A control laboratory capable of performing the tests listed in the table is required to ensure proper and consistent control of process operation.

Some industry standards for oil products, such as engine oils and hydraulic fluids, require performance tests. This is because the physical and chemical tests alone do not predict the suitability of the final product for the intended application. Whether a re-refined oil is satisfactory for these applications cannot be determined until the oil is blended with the required additives and the applicable performance tests run. However, re-refined oils produced with care are certainly good candidates as base oils for such products. Once qualified through the performance tests, re-refined oils should continue to be satisfactory base oils provided the process control mentioned above is maintained.

The character of the waste oil used in any process is an important factor in determining the quality of the re-refined oil which is produced. This would be particularly so in an Acid/Clay process.



It should be less so in a Distillation/Clay process and of still lesser importance in one involving distillation and hydrogen treatment. This is because removal of contaminants in the Acid/Clay process is achieved by chemical reactions; in the distillation processes, contaminants are removed by physical means. Waste oil composed of a mixture of used industrial oils would be expected to be more difficult to process than feedstocks consisting of used motor oils only. Different industrial oils contain a great variety of additives such as the various fatty-oil compounds used in cutting oils, rolling oils, gear oils, etc. These used industrial oils can contain emulsions with water which may be difficult to break. As a consequence, re-refining of used industrial oils must normally be carried out under conditions where a single type of waste oil is processed in a separate batch operation.



3. ENVIRONMENTAL IMPACTS OF BY-PRODUCTS OF WASTE OIL RE-REFINING PROCESSES

3.1 Introduction

This chapter analyzes the environmental risks associated with alternative methods of disposal of the by-products of re-refining processes. By-products of re-refining processes are composed of materials which are either present as contaminants in the waste oil feedstock or are introduced into the process stream as a part of the re-refining operation.

By-products generated in the course of re-refining are not generally recovered for reuse because:

- They may have little if any intrinsic value (e.g., spent clay).
- They may have intrinsic value, but direct use may require unacceptable costs in order to meet environmental standards (e.g., acid sludge as potential fuel).
- They may have intrinsic value, but recovery may pose excessive economic costs (e.g., extraction of sulfuric acid from acid sludge).

The re-refining methods considered in this chapter are:

- Acid/Clay
- Extraction/Acid/Clay
- Distillation/Clay
- Distillation/Hydrotreating

All of these processes have the common objective of removing from waste oil the various contaminants and decomposition products introduced into or formed within the original lubricating oil during its service life. Blends of the resulting base stock, appropriate additives and



other oils can closely approximate the quality of the original lubricating oil.

The discussion in this chapter focuses on the re-refining of crankcase drainings for two reasons. First, a large fraction of the waste oil available for processing by re-refiners in Canada is automotive and commercial transportation crankcase oil. According to the Petroleum Association for Conservation of the Canadian Environment (PACE),¹ 22,000,000 gallons of such oils were collected in 1970 and, of this amount, 5,200,000 gallons were re-refined within Canada. This latter figure agrees fairly well with the estimate of 5 to 6 million gallons made by Environment Canada.² Thus, it is clear that used crankcase oil currently constitutes a principal source of feedstock for Canadian re-refineries.

Second, in terms of potential environmental risk, used crankcase oil probably represents a rather greater hazard than the industrial waste oils which are available for re-refining. Crankcase oils typically have a lead content of approximately 1 percent and contain specific polynuclear aromatics (PNAs), such as benzo-a-pyrene (BaP), known to be potentially carcinogenic. It is true, of course, that process by-products, such as the acid sludge generated in the Acid/Clay re-refining process, can pose environmental problems independently of whether the feedstock contains lead. The presence of the metal is, however, a complicating factor.



3.2 Summaries of Re-refining Processes

The re-refining processes assessed in this chapter have been described earlier in this Report. Accordingly, only critical issues are summarized for convenience.

3.2.1 Acid/Clay

The waste oils are initially flashed at about 300°F. The light oil/water overhead is separated and the oil fraction is retained for fuel. Following dehydration, the feedstock is treated with sulfuric acid for about 24-48 hours at about 100°F. This process coagulates oxidized oil contaminants and precipitates most of the metals contained in the feedstock. The oxidation products, metals, and acid form a sludge from which the oil is then separated. The treated oil is steam stripped and further refined by treatment with clay to remove most of the residual color bodies and colloidal carbon. The clarified oil is recovered from the oil/clay mixture by filtration.

Typically, the amount of sulfuric acid (92-98% H_2SO_4) employed in the process varies from 4 percent to 7 percent by volume. One factor affecting acid consumption is the residual moisture content of the oil following dehydration. A higher residual moisture content requires that greater volumes of acid be used. The amount of clay used for clarification is about 0.5 pounds per Imperial gallon of acid treated oil.



3.2.2 Extraction/Acid/Clay

Following a dehydration process (described above), the feedstock is treated with liquid propane (in the ration of about 15/1) which results in an oil/propane solution. The insoluble materials, such as metals, form a precipitate in the process. The propane is separated from the oil by distillation and is liquefied for reuse. The extracted oil is then treated with sulfuric acid and clay in the manner described above.

A considerable fraction of the total contaminants is removed during the solvent extraction process. Therefore, the relative quantities of acid and clay required are considerably less than those used in the Acid/Clay process. The sulfuric acid requirement is about 2 percent by volume and the clay requirement about 0.2 pounds per Imperial gallon of acid treated oil.

3.2.3 Distillation/Clay

The waste oils are initially dehydrated. The flash tower bottoms are supplemented with light oil (about 20% by volume) and a small amount of caustic (0.2% to 2.0%). These additives break down any residual emulsion present and precipitate some of the included solids. The resulting sludge is removed by centrifugation. The centrifuged oil is distilled. The low boiling point fraction is recycled for dilution with the caustic and any excess is used for fuel. Middle cuts, which are to be used for lubricating oil blending stock, are clarified by treatment with clay and are filtered as in the above processes.



The amount of clay required in this process is about 0.15 pounds per Imperial gallon of vacuum distilled oil. The distillate bottoms, which contain most of the ash content of the original feed, may be used for fuel or as an asphalt blend component.

In this process, the caustic addition-centrifuging treatment is not essential; however, it eliminates much of the material which can cause objectionable corrosion and fouling in the distillation column and related equipment.

3.2.4 Distillation/Hydrotreating

This method is similar to the Distillation/Clay re-refining process except for the final treatment stage. Instead of treatment with clay, the distillate is catalytically treated with hydrogen. The hydrogen reacts with impurities containing oxygen and nitrogen. Volatiles are removed from the hydrotreated oil by steam stripping. The unreacted hydrogen is recycled.

3.3 Overview of Process By-products

As stated earlier, the by-products of oil re-refining processes can be divided into two principal groups:

- Contaminants present in the waste oil which are separated from the feedstock during the re-refining process.
- Materials introduced during the re-refining process which are not constituents of the waste oil feedstock.

In this discussion, by-products of the first group will be classified as "endogenous" and those of the second group as "exogenous".



For a given feedstock composition, the endogenous waste components represent an irreducible minimum load which is independent of the particular re-refining method employed. However, the four different processes considered here vary with respect to both the amounts of the exogenous by-products they generate, and the levels of potential environmental risk associated with disposal of these wastes. Accordingly, if minimization of environmental impact were to be the only criterion in the selection of a re-refining process (that is, if economic, technological and other nonenvironmental considerations were to be ignored), it would be reasonable to favor that method where the production of hazardous wastes per unit of re-refined oil produced is the least, considering both by-product quantity and the hazard presented.

On the basis of the above criterion, even in advance of the following detailed analysis, the Acid/Clay process is probably the least environmentally appealing of the four re-refining methods under evaluation. The principal reason for this is, of course, the acid sludge whose disposal presents a serious problem. The spent oily clay also requires disposal, although it is inherently less environmentally hazardous than the acid sludge.

Although the by-products of the Extraction/Acid/Clay process also include acid sludge and spent clay, the quantities generated per unit of refined oil produced are, as noted earlier, substantially smaller than those associated with the Acid/Clay procedure. Therefore, the Extraction/Acid/Clay method may be considered environmentally preferable to the Acid/Clay process.



3.4 Detailed Estimates of Re-refining By-product Quantities

The following sections provide quantitative estimates of the rates of production of by-products for the four re-refining processes. The design and operation of the model facilities are described in Chapter 1.

For a given type of waste oil, such as used gasoline engine crankcase oil, the exact composition may vary considerably from source to source. Such variations may arise from differences in average oil service life (the drain interval), the average lead content of the fuel used in the vehicles from which the used oil was removed, the condition of the engine lubricated and the amount of water present in the oil.

The quantities of wastes generated by the four processes under review in this study have been estimated by assuming that the waste oil feed of 16,667 Imperial gallons per day has the following composition:

<u>Component</u>	<u>Percent Volume</u>
Water	3.5%
Naphtha fraction	5.0
Diesel fraction	1.5
Lube oil fraction	<u>90.0</u>
Total	100.0%

The data presented below were obtained from the detailed material balances described in Chapter 1.



3.4.1 Acid/Clay Process

Estimates for quantities of wastes generated are:

<u>Waste Product</u>	<u>Per Day</u>	<u>Per Imperial Gallon of Product</u>
Acid Sludge--pounds	41,230	3.44
Oily clay--pounds	7,920	0.66
Endogenous water, Imperial gallons	583	0.0485
Exogenous water, Imperial gallons	750	0.0625
Total process water	1,333	0.111

The distribution of oil to the waste streams and the re-refined product is shown below. Percentage loss is based on the lube oil fraction contained in the waste oil feed.

	<u>Imperial Gallons Per Day</u>	<u>Percent Volume</u>
Oil lost to acid sludge	2,795	18.6%
Oil lost to clay	205	1.4
Re-refined product	<u>12,000</u>	<u>80.0</u>
Lube oil in feed	15,000*	100.0%

*15,000 Imperial gallons calculated by multiplying the lube oil fraction, assumed to be 90%, times 16,667 Imperial gallons of feedstock per day. This means that the water and naphtha and diesel fraction is 10% of the total volume. Refer to Chapter 1 for assumptions.

3.4.2 Extraction/Acid/Clay Process

Estimates for quantities of wastes generated are:

	<u>Per Day</u>	<u>Per Imperial Gallon of Product</u>
High ash residue (without cutter), Imperial gallons	558	0.040
Acid sludge--pounds	10,080	0.726
Oily clay--pounds	3,216	0.23
Propane (vapor loss)--pounds	440	0.032
Endogenous water, Imperial gallons	583	0.042
Exogenous water, Imperial gallons	930	0.067
Total process water, Imperial gallons	1,513	0.109



The estimated distribution of lube oil to the waste streams and product is:

	<u>Imperial Gallons Per Day</u>	<u>Percent Volume</u>
Oil lost to high ash residue	558	3.73%
Oil lost to acid sludge	550	3.33
Oil lost to clay	67	.44
Re-refined product	<u>13,875</u>	<u>92.50</u>
Lube oil in feed	15,000	100.00%

3.4.3 Distillation/Clay Process

Estimates for quantities of wastes generated are:

	<u>Per Day</u>	<u>Per Imperial Gallon of Product</u>
Caustic sludge--pounds	2,400	0.189
High ash residue, Imperial gallons	2,136	0.169
Oily clay--pounds	2,568	0.203
Endogenous water, Imperial gallons	583	0.046
Exogenous water, Imperial gallons	1,392	0.110
Total process water, Imperial gallons	1,963	0.156

The estimated distribution of the lube oil to waste streams and product is:

	<u>Imperial Gallons Per Day</u>	<u>Percent Volume</u>
Oil lost to caustic sludge	130	0.87%
Oil lost to high ash residue	2,136	14.28
Oil lost to clay	67	0.45
Re-refined product	<u>12,667</u>	<u>84.40</u>
Lube oil in feed	15,000	100.00%



3.4.4 Distillation/Hydrotreating Process

Estimates for quantities of wastes generated are:

	<u>Per Day</u>	<u>Per Imperial Gallon of Product</u>
Caustic sludge--pounds	2,400	0.189
High ash residue, Imperial gallons	2,136	0.169
Endogenous water, Imperial gallons	583	0.046
Exogenous water, Imperial gallons	2,112	0.167
Total process water, Imperial gallons	2,695	0.213

The estimated distribution of lube oil to the waste streams and re-refined product is:

	<u>Imperial Gallons Per Day</u>	<u>Percent Volume</u>
Oil lost to caustic sludge	130	0.87%
Oil lost to high ash residue	2,136	14.28
Oil shrinkage through hydro- treating	67	0.45
Re-refined product	<u>12,667</u>	<u>84.40</u>
Lube oil in feed	15,000	100.00%

3.4.5 Lead Distribution

For the analyses presented here, the waste oil was assumed to have a lead content of 1% by weight. Although this concentration is somewhat higher than that usually encountered, it is not uncommon and from a conservative environmental orientation is considered realistic.

Assuming that the waste lube oil feed contains one percent lead, about 1,300 pounds of lead per day are input to each of the model plants. The following paragraphs describe the distribution of lead in the waste streams.



In the Acid/Clay process, essentially all the lead is removed in the acid sludge. The acid sludge contains about 3.2% lead by weight.

In the Extraction/Acid/Clay process no data are available which show the lead distribution in the waste streams. A reasonable assumption is that 80% of the lead is contained in the high ash residue and 20% in the acid sludge. On this basis, the high ash residue would contain 15%* lead by weight as produced and 11%* lead by weight after addition of cutter stock. Under these conditions, the acid sludge would contain about 2.5% lead by weight.

Again, no data on lead distribution in the waste streams from the two distillation processes are available. Assuming that one-half the lead is contained in the caustic sludge and that one-half the lead is contained in the high ash fuel oil, the lead contents of the caustic sludge and the high ash residue would be about 25% by weight and 3% by weight, respectively.*

3.5 Implications of Preceding Analyses

This section addresses the environmental implications of the analyses of by-products of re-refining processes presented in Section 3.4.

* The estimated quantities of sludges produced were not based on the assumption of a high lead content feedstock, as is postulated in these example calculations. The high lead content would probably be accompanied by more sludge formation, which in turn would reduce the percentage of lead in the waste stream.



3.5.1 Process Efficiency

The estimated process efficiencies are indicative of the performance of a properly designed and operated facility processing a waste oil having the composition as described in Section 3.4. Less efficient operations would increase the amounts of wastes generated per Imperial gallon of product.

3.5.2 Daily Processing Volume

The analyses in Section 3.4 were based on a daily feedstock volume of 16,667 Imperial gallons. Assuming 330 days a year operation, this would represent an annual feedstock volume of approximately 5 million Imperial gallons. By-product production rates for alternative capacities of operation (see Chapter 2 for economic comparisons) may be estimated by scaling the figures presented earlier in proportion to the waste oil feed rates.

3.5.3 Data Base Uncertainties

The preceding analysis has been restricted to those waste products for which quantitative estimates can reasonably be made. Even in these cases, however, certain assumptions were sometimes necessary, such as the postulated lead distribution between centrifuge sludge and high ash residue in the Distillation/Clay and Distillation/Hydrotreating processes. With respect to some waste by-products (such as sulfur oxides which may be vented to the atmosphere in the operation of the



Acid/Clay process), no data were found which would permit even approximations of the probable amounts generated.*

3.5.4 Non-lead Waste Oil Contaminants

In addition to lead, waste crankcase oil may also contain a number of other metallic contaminants, most of which are constituents of the additives blended with the original base oil. According to the American Petroleum Institute, typical concentrations of these metals in waste automotive oil are:

<u>Metal</u>	<u>Concentration (by weight)</u>
Calcium	0.17%
Zinc	0.08%
Barium	568 ppm
Iron	356 ppm
Vanadium	5 ppm

Reported average concentrations of other metals include copper (26 ppm), magnesium (252 ppm), sodium (148 ppm) and aluminum (11 ppm). It should be noted that the Ontario Ministry of the Environment has published concentration standards for wastewater discharges of copper, as well as for lead (1.0 mg/l), both of which are waste oil contaminants. In a properly operated re-refining plant, however, environmentally significant amounts of the metals in the waste oil should not appear in the process water stream. Of all the metals present in waste oil, lead has been singled out for special treatment in this report because of its toxicity and its relatively high concentration in automobile crankcase drainings.

* It should be recognized that the amount of a give waste generated is not necessarily the amount which is released to the environment. For example, in the case of SO_2 and SO_3 , these gases could be treated with lime water ($\text{Ca}(\text{OH})_2$) for conversion to the more "environmentally manageable" calcium salts.



3.5.5 High Ash Residue

In the analyses in Section 3.4, the question of whether the high ash residue, generated during the two distillation processes, should be treated as a product or by-product was not explicitly addressed. This fraction, often termed "high ash fuel residue," is so named because it burns readily and has a high heat content. It does, however, contain a higher lead concentration than that of the original feedstock (3% by weight or more versus 1% in our example analyses). Therefore, its use as a fuel without prior removal of the lead or without suitable control measures for preventing lead emissions to the atmosphere during its combustion may pose environmental risks. Other possible uses, such as its incorporation within asphaltic products, appear to pose little, if any, environmental threat. Accordingly, it is possible to view the high ash residue as either a product or by-product, depending on the type and circumstances of use. In the economic evaluations presented in Chapter 2, the high ash residue is assumed to have a value as a fuel. However, the value has been discounted to reflect the non-combustible content, as well as the restricted usage potential.

3.6 By-product Transport Modes, Receptor Effects and Potential Damage Implications

In addition to rates of by-product formation, a complete environmental assessment of any process must address by-product transport through the environment and the effects on and damages to exposed populations. The discussion below provides a review of these considerations for the important by-products generated by the four re-refining processes.



In this description the acid content of sludge refers to the amount of acid introduced into the process to produce the sludge stream. The waste stream is treated as though all the acid is present as "free acid." Actually most of the acid is chemically bound to other compounds which will lower the water solubility of the acid radical. On this basis the values of acid available for soil percolation are conservative. The same comment applies to caustic in caustic sludges and to a lesser extent to oil in acid and caustic sludges.

3.6.1 Acid/Clay Process

The acid sludge generated by this process is the prime environmentally hazardous by-product. Sulphuric acid constitutes about 23% of the sludge on a volumetric basis. In terms of weight, this percentage is considerably greater because of the high density of the acid. In view of its acid content, even independently of the lead constituent (about 5 ounces per Imperial gallon of sludge), acid sludge is clearly a "hazardous waste" as defined in Ontario Regulation 375/70.³ Operation of the reference Acid/Clay re-refinery for a single day would produce 815 Imperial gallons of waste acid (assuming 18.4 pounds per Imperial gallon of sulphuric acid and the use of one pound of acid per Imperial gallon of feedstock).

Land disposal sites are commonly employed as repositories for acid sludge. Under Ontario law (The Environmental Protection Act, 1971: Part V) the use of waste disposal sites (including their establishment, alteration and extension) requires a certificate of approval, or at least a provisional certificate of approval. Since sulphuric acid



is water soluble, a potential exists for its percolation through soil surrounding the disposal site area. While the acid is toxic to most life forms, its damage capability would, in a large measure, depend on the magnitudes of the resources (e.g. groundwater) and populations at risk in the exposure area. The extent of percolation depends on such factors as:

- Exposure of sludge to rain or melted snow.
- Permeability of the disposal site (as determined by soil porosity).
- The extent of mixing of sludge with other, relatively inert wastes which may absorb or otherwise "bind" the acid.

Percolation of acid through soil can lead to pollution of the underlying groundwater. The Groundwater Probability hydrogeologic provincial maps issued by the Water Quality Branch of the Ontario Ministry of the Environment, indicate that the overburden is principally clay in many areas with a depth of a hundred feet or more. In some regions, however, the overburden is predominantly sandy and considerably less thick. Such variations may occur within a given county so that it is impossible to generalize with respect to Ontario as a whole. However, since the risk of infiltration of sulfuric acid releases into underlying groundwater is determined by the character and thickness of the overburden, these considerations must play a major role in selecting environmentally safe disposal areas.

The practice of mixing acid sludge with dry refuse appears preferable to merely "dumping" the waste. In Germany, sludge deposits in landfill sites are alternately layered with refuse material. It is claimed that



this method eliminates a significant portion of the potential environmental hazard.⁴

Chemical neutralization of the acid component of sludge by mixing with lime is considered to be an attractive approach from an environmental viewpoint. However, experimental studies have shown that the quantity of lime required to neutralize a given amount of H_2SO_4 in sludge is greater than stoichiometric calculations would indicate, possibly because the acid is mixed with oil residues which interfere with contact between the acid and the lime. In general, complete neutralization of the acid requires about 2 to 2.5 times the theoretical quantity of lime. Sludges neutralized with lime are dry and somewhat lumpy, relatively inert and have a pH between 7 and 8.

Sludge disposal by incineration has been practiced, especially in Europe, but is not recommended unless adequate air pollution control measures are employed. Acid sludge may be incinerated directly or following lime neutralization. In either case, sulfur oxides and metallic particulates are produced. Without adequate controls these materials will be released to the air.

The lead and oil components of the acid sludge must also be considered. Lead, together with most of the other metals present in the waste oil, is converted to the sulfate during the acid treatment. Lead sulfate is relatively insoluble in water. A saturated solution at low temperatures contains about 4 mg lead per 100 ml. Thus, although it is unlikely to percolate through soil as readily as sulphuric acid, significant concentrations of lead sulfate in the soil water could result.



(As a reference comparison, the Ministry of the Environment's Objectives for the Control of Industrial Waste Discharges in Ontario set an upper limit for lead of 1.0 mg/l, which is only about 1/40th the maximum concentration of the metal which could exist in the moisture content of soil in the proximity of an acid sludge disposal site.⁵) It is, however, uncertain how much of the lead sulfate may become bound to soil particles with consequent limitation of its "migratory" range. With regard to lead sulphate, a critical issue in the selection of a disposal site is the soil pH. Adsorption is much less pronounced with a pH value of 6 or less. For example, road oiling in Mississippi, using waste automotive crankcase oil, did not appear to induce lead contamination of the local groundwater.⁶ (Groundwater is rigorously monitored in this state so that it is unlikely that lead contamination would have been undetected.) In any case, leaching of lead into soil in the area of a disposal site could result in takeup of the metal by local vegetation. (Increases in the normal concentrations of lead in vegetation were noted in the EPA Edison Laboratory road oiling experiment.⁷) The damage implications of this possibility are not clear since waste disposal sites certified for hazardous materials could not be located close to agricultural areas.

The oil constituent of the sludge occurs as a component of a tarry mass rather than as a freely flowing liquid. Its potential for percolation through soil would appear limited. Such percolation as might take place would be slow. Further, biodegradation of the oil by soil microorganisms would limit or eliminate the risk of groundwater pollution. In overview, it must be appreciated that the "acid sludge problem" derives not only



from the inherent toxicity of the sulfuric acid and lead components as such, but also from the amounts of these wastes which would be generated by an economically sized re-refinery. Assuming that 815 Imperial gallons per day of H_2SO_4 are consumed and that the re-refinery operates 330 days a year (an operation rate used in the base case of the economic evaluations), about 268,950 Imperial gallons of acid will be available for disposal in a single year. The corresponding amount of waste lead generated in 330 days of operation would be about 495,000 pounds (assuming that 0.125 pounds of lead waste are produced for each Imperial gallon of product).

Use of lagoons for acid sludge disposal has been practiced at several locations in the United States. This procedure is not considered desirable because (a) it does not offer a permanent solution to the disposal problem as it is essentially a postponement measure and (b) the lagooned sludge represents an environmental danger due to "acts of God," such as storms and floods, as well as human intervention, such as errors in design and improper operation.

As stated earlier, the oily clay does not present a significant environmental problem. Disposal to landfill is common, although incineration is also possible. Incineration of this by-product poses a much lower environmental risk than the uncontrolled incineration of acid sludge. This is because the clay contains no H_2SO_4 and very little lead or other metals. Assuming that 0.66 pounds of oily clay are generated per Imperial gallon of re-refined oil produced and that the reference re-refinery



operates 330 days per year, approximately 2.6 million pounds of oily clay will be produced.

The wastewater generated during the re-refining process includes an endogenous component which was originally a constituent of the feedstock and an exogenous component introduced during processing operations. The latter includes water which has contacted oil, such as condensed stripping steam or water from the vent gas scrubber. This component does not include surface drainage or blowdown from boilers or cooling towers. In all four re-refining processes, the endogenous water component is separated from the light oil fraction during dehydration of the feedstock. The character and concentrations of the pollutants contained in the aggregate wastewater may vary considerably, depending on the re-refining process and the composition of the feedstock. Reliable data pertaining to the quality of process waste water are not abundant. A study performed for the U.S. Environmental Protection Agency presents analyses of wastewater streams for one oil re-refining operation (Acid/Clay).⁸ The pollutant concentrations shown are suspect, however, because the crude sampling methods employed may have produced erroneously high values. Also, due to inaccessibility, samples could not be obtained at the point at which the wastewater was released to the sewer system. The following table shows the maximum observed values for the various pollutants together with the Ontario Ministry of the Environment's recommended objectives for industrial waste discharges into receiving waters.



<u>Pollutant</u>	<u>Maximum Concentration</u>	<u>Ontario Recommended Objective⁵</u>
BOD	6 mg/l	15 mg/l
Oil	3,629 ppm	15 ppm
Phenols	92 ppm	20 ppb
Suspended solids	401 ppm	15 ppm

The lowest observed pH was 4.1 which is below the Ontario desired lower limit of 5.5.

On the basis of the Ontario desired effluent quality standards, it is clear that wastewater of the above quality could not legally be discharged into receiving waters. Further, it is unlikely that the wastewater would qualify under the restrictions typically imposed by municipal wastewater treatment facilities. For example, these restrictions normally limit the oil and grease content of wastewaters to 100 ppm, a figure far below the maximum oil concentration listed above. As was pointed out, however, the pollutant concentrations which were reported may be greatly in error.

In general, it is unlikely that even under the best attainable operating conditions, process wastewater would exhibit sufficiently low pollutant concentrations to permit direct discharge to receiving waters. Under such conditions, though, a water quality compatible with restrictions of municipal waste treatment facilities could be achieved. For example, the report cited above presents data for a marine waste oil processing operation in which the contaminant levels present in the waste process water effluent were well within customary limits imposed by municipal treatment facilities. Accordingly, re-refining process wastewater should not pose an environmental threat if water quality is monitored at the point of discharge to the public collection system.



3.6.2 Extraction/Acid/Clay Process

The by-products generated in this process differ from those resulting from Acid/Clay waste oil re-refining. The differences are:

- a. Less sulfuric acid is used in this method. On the basis of operating 330 days each year, the annual output of H_2SO_4 in the acid sludge would be about 85,250 Imperial gallons as compared with 268,950 Imperial gallons in the Acid/Clay process.
- b. Less clay is used. The computed annual waste, on the above basis, is 1,061,280 pounds as compared with 2,613,600 pounds in the Acid/Clay process.
- c. The oil losses to both the acid sludge and the oily clay are substantially lower, by 83% and 68%, respectively.
- d. The Extraction/Acid/Clay process generates a high ash residue which is not formed in the course of Acid/Clay re-refining. This residue contains about 80% of the lead that was present in the feedstock.

The environmental implications of the disposal of acid sludge and oily clay were presented in Section 3.6.1. In view of the lower rates of generation of these wastes in the Extraction/Acid/Clay process, the risk is quantitatively lower. However, the problems associated with the safe disposal of 85,250 gallons of acid annually are still appreciable.

The environmental implications of the disposal of high ash residue have already been outlined in Section 3.5.5. The lead content of this material is appreciable. In the model re-refinery, the lead content of the high ash residue was 15% by weight. In practice it may be even higher. Clearly, the environmental risk of improper disposal of the residue can be significant. As pointed out, direct burning, in the absence of either pretreatment to remove lead or effective measures



for the retention of particulates in the flue gases, will result in lead emissions to the atmosphere. This is the case whether the residue is incinerated for the sake of disposal as such, or whether it is burned for its intrinsic heat value. Obviously, those disposal methods which permit resource recovery under conditions which minimize lead pollution of the ambient air are to be favored. One such method already identified is the use of high ash residue in asphalt manufacturing. Another is the use of the residue as a fuel in cement kilns. Still another is combustion in lead reverberatory furnaces in which lead and the heating value of the residue can be recovered. The annual quantity of lead contained in the residue would be approximately 357,500 pounds. Serious consideration of an investment in the Extraction/Acid/Clay process should include an evaluation of the economics of lead recovery from the high ash residue.

3.6.3 Distillation/Clay Process

Neither this process nor the Distillation/Hydrotreating process discussed in Section 3.6.4 generate acid sludge as a by-product. Both, however, produce caustic wastes and high ash residues which contain lead. Operation of the reference Distillation/Clay facility for 330 days a year would produce the following wastes:

<u>Waste By-product</u>	<u>Annual Amount</u>
Caustic to caustic sludge--pounds	440,000
Oil to caustic sludge, Imperial gallons	44,000
Lead to caustic sludge--pounds	220,000
Oil to oily clay, Imperial gallons	24,750
Clay to oily clay--pounds	660,000
Lead to high ash residue--pounds	220,000
Process water, Imperial gallons	687,550



The caustic centrifuge sludge generated during this process is potentially environmentally hazardous. As in the case of acid sludge, disposal is commonly accomplished by landfill. The observations made earlier with respect to the possibility of sulfuric acid percolation through soil from the disposal site, including the possible contamination of groundwater, also apply. Disposal of caustic sludge in an unlined and uncovered landfill situated in soil of even moderate porosity could result in the leaching of over 220 tons of NaOH per year into neighboring ground. With sufficient rainfall or snow runoff, the soil pH would rise substantially.

Since relevant experimental data are not available, it is difficult to make a quantitative comparison of the environmental risks posed by the lead contained in caustic and acid sludges. The considerations involved in this question are the following: In the case of acid sludge, most of the lead is present as the sulfate, which is relatively insoluble (4 mg/100 gms water). In the case of caustic sludge, the lead can react with the NaOH to form lead oxide (PbO). PbO is less soluble in water than the sulfate (about 1.7 mg/100 gms water). However, it is quite soluble in alkali which suggests the possibility of its percolation in dissolved form. The range of lead migration will also be influenced by the degree to which it is adsorbed on soil particle surfaces. Lead adsorption is reduced at soil pH levels of 6 and less. Thus, although lead sulfate from acid sludge is relatively insoluble, its potential for migration through soil is less likely to be restricted by adsorption than that of lead oxide (PbO) dissolved in NaOH leached from caustic



sludge. Experimental data are needed to determine whether the rate of percolation of lead sulfate from acid sludge is greater or less than the rate of percolation of lead oxide from caustic sludge.

An additional consideration is the fact that these sludges do not consist purely of free H_2SO_4 and lead or of free NaOH and lead. They also contain significant amounts of other constituents, particularly oil. The percentage of oily constituents, by weight, varies for sludges generated in the different re-refining processes examined as follows:

<u>Sludge Type</u>	<u>Percent Oil (by weight)</u>
Acid (Acid/Clay process)	61%
Acid (Extraction/Acid/Clay process)	43
Caustic (both distillation processes)	36

The effect of such relatively high concentrations of oil and oily materials in the sludges is to retard the rate at which the other sludge constituents will be leached out by ambient moisture or percolate into the soil directly.

The high ash residue generated during the Distillation/Clay re-refining process is assumed to contain about 50% of the lead contained in the waste oil. On an annual basis, this amounts to 220,000 pounds, or about 62% of that which is contained in the high ash residue resulting from the Extraction/Acid/Clay process. Even at this lower level, its recovery as a valuable resource seems to warrant consideration.

The comments made earlier with respect to disposal of oily clay generated during the other re-refining process also apply. However, the oily constituent of the spent clay amounts to only about 24,750 Imperial gallons annually (as compared with 68,750 Imperial gallons for the Acid/Clay



process). The annual generation of spent clay is about 660,000 pounds. Beneficial applications for this waste should be investigated.

3.6.4 Distillation/Hydrotreating Process

This process differs from the Distillation/Clay process in that catalytic hydrotreating replaces the clay finishing step. With the possible exception of wastewater, the Distillation/Hydrotreating process generates smaller quantities of hazardous wastes than any of the other re-refining processes investigated. With the exception of spent clay, which is not generated as a product in the Distillation/Hydrotreating process, rates of solid waste generation are the same as for the Distillation/Clay process.

3.7 Conclusions

It is difficult to make quantitative assessments of the environmental impacts of the disposal of by-products of re-refining processes without specifying (a) the technical quality of plant operations, (b) the type and concentration of constituents in the waste oil feedstock, (c) the methods of by-product disposal employed and (d) the populations and/or resources at risk in locations where hazardous disposal practices may be followed. However, the following qualitative assessments can be made:

- a. Virtually none of the by-products discussed is acceptable for direct discharge into receiving waters under Ontario law, including waste process water. Such discharges could be expected to be lethal to fish and other aquatic organisms in the immediate localities impacted by the effluent. The extent of damage would, aside from the character of the by-product involved, depend on its discharge rate and its dilution as a function of distance from the discharge point.



- b. If monetary and resource costs are not taken into account, then any of the re-refining processes discussed in this Section could be made "environmentally safe," providing that appropriate waste management practices were followed.
- c. In terms of the landfill disposal practice, the primary potential transport mode is by percolation through soil at the disposal site. Aside from the threat posed to soil biota, there is also the possibility of infiltration of certain by-products (acid, alkali and metals, particularly lead) into groundwater. The rate of infiltration is dependent on the thickness and permeability of the overburden. (Effective percolation of mercury,* for example, through six feet of silt has been computed to require twelve years.⁹ The slowness of percolation is in large part due to absorption of the metal by soil during passage.)
- d. For the acid type re-refining processes, pollutant transport by air could be significant if vented oxides of sulfur (SO_2 and SO_3) are not controlled. Sulfur oxides are known to cause respiratory disease in humans and numerous animal species and are also injurious to vegetation. Specific damage effects would depend on the ambient concentrations generated and the populations exposed. Under Ontario Regulation 873/74, the maximum 24-hour permissible concentration of SO_2 in the ambient air is 275 ug/m^3 (the equivalent U.S. EPA standard is 365 ug/m^3).³

Propane releases to the atmosphere, which occur in the Extraction/Acid/Clay process, do not pose a significant environmental hazard. The Ontario regulation cited above does not contain a standard for ambient hydrocarbons.

- e. By considering the inherent environmental hazards associated with the by-products discussed, it is possible to arrive at a rank ordering which reflects the relative levels of these hazards. (Note the qualification implied in the word "inherent," above, because the actual hazard will depend on the by-product control or disposal method as well as on the identity of the waste.)

The listing that follows proceeds from the most inherently environmentally hazardous to the least hazardous.

- Acid sludge (ranking based on H_2SO_4 and lead content).
- Caustic sludge (ranking based on NaOH and lead content).

* An "effective percolation" of mercury is a 50% concentration at a six foot depth.



- Sulfur oxide emissions (ranking based on known biotic effects).
- High ash residue (ranking based on lead content).
- Spent clay (ranking based on intrinsic inertness of the clay, although the oil constituent is not environmentally bland).
- Process wastewater (ranking based on the consideration that most process wastewater discharges should be acceptable to municipal facilities).
- Propane, hydrogen (releases which may occur are not regarded as environmentally significant).

Lead is considered to be one of the most toxic of the process by-products but is not ranked independently here because it occurs in association with other wastes.

The Ontario water quality regulations, applicable to streams, set an upper limit of 50 ppb for lead, which is a measure of the environmental concern associated with this metal.¹⁰ Unlike some toxic pollutants (e.g., SO₂), lead tends to accumulate in organisms, including man, on repeated exposure so that even quite low doses, if repetitive, can be significant. The polynuclear aromatics (PNAs) associated with waste oil, some of which are known to have carcinogenic implications, were not discussed in this analysis because of insufficient data related to specific re-refining processes. They are, however, treated in the following Chapter of this Report.

- f. On the basis of the analysis presented in this Section, the oil re-refining processes considered are ranked below in terms of decreasing potential environmental effect.

Acid/Clay Process

Ranking based on the generation of the largest volume of lead-containing acid sludge and on the potential for sulfur oxide emissions.

Extraction/Acid/Clay Process

Ranking based on reduced use of sulfuric acid with consequently lower generation of acid sludge and of sulfur oxides. Although the sludge contains relatively less lead, this is offset by the lead-containing high ash residue.



Distillation/Clay

Ranking based on elimination of H_2SO_4 as a process ingredient with consequent elimination of acid sludge and sulfur oxide emissions.

Distillation/Hydrotreating

Ranking based on the elimination of spent clay as a waste by-product. This is considered to be only a marginal advantage over the Distillation/Clay method because the spent clay is a space-occupying nuisance rather than a serious environmental hazard.

- g. In terms of Ontario regulations, haphazard releases or careless disposal of most of the by-products considered would constitute violations. Conversely, as stated earlier, if costs are ignored, any of these processes could be brought into conformity with the regulations. The question is really that of the relative ease of accomplishing such conformity, as well as the magnitude of hazard involved in the event of failure of one or more control technologies employed (e.g., emissions controls, impervious disposal site liners, etc.). From this viewpoint, either of the distillation methods is preferred with some advantage accorded to the Distillation/Hydrotreating process.



CHAPTER THREE

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4. SURVEY OF ALTERNATIVE AVAILABLE TECHNOLOGY FOR DISPOSAL OR USE OF WASTE OIL, INCLUDING ANALYSIS OF ENVIRONMENTAL IMPACT

This chapter addresses alternative methods of waste oil "disposal" or "use" other than re-refining. In the context of this discussion, "disposal" methods are those which address waste oil not as a potential resource but rather as a burden. "Use" technologies, on the other hand, are aimed at the recovery of some economic value inherent in the oil, whether this be in the form of energy or material.

In this study, the "disposal" methods reviewed are:

- a. Biodegradation by soil microorganisms.
- b. Thermal destruction without useful heat recovery.

"Useful" or potential applications of waste oil examined here include:

- a. Blending with fuel oil.
- b. Blending with coal.
- c. Use as a fuel in cement plants.
- d. Use as a fuel in municipal waste incinerators.
- e. Use in asphalt manufacture.
- f. Use as a dust suppressant road oil.
- g. Blending with diesel fuel.

The above methods and technologies are summarized and assessed, as available data permit, in terms of their environmental implications. This review is based, in large part, on published reports of experiments designed to test these disposal and use methods. These reports vary



considerably with respect to the comprehensiveness and depth with which the technologies discussed are analyzed. In some instances, the information presented is essentially qualitative. Where quantitative data are provided, these often relate to specific demonstration projects and thus reflect particular sets of experimental conditions which may not be applied uniformly. Further, these data are usually insufficient to permit as comprehensive an evaluation as desirable of the environmental effects of the method or technology addressed. For example, various studies have been performed of the use of waste oil as a fuel. In most instances these studies included consideration of lead emissions to the atmosphere during the fuel burn and, in some, during soot blowing. However, the possible implications of waste oil PNA content are not addressed explicitly, even from a qualitative viewpoint.

The following discussions in this chapter survey the various waste oil disposal and use options identified above, with emphasis directed to their apparent or prospective environmental impacts, as opposed to their technological details. Where feasible, these impacts are assessed in terms of prevailing Ontario environmental regulations and standards. The discussions of individual disposal and use options are followed by a summary evaluation in which the alternatives are categorized on the basis of the degree of potential environmental hazard they present. This chapter concludes with a consideration of waste oil PNA content and its possible implications.



4.1 Waste Oil Disposal Alternatives

4.1.1 Biodegradation by Soil Microorganisms

This disposal method consists essentially of land spreading conducted under conditions which favor biodecomposition of the oil. As is true for thermal destruction, biodegradation has as its objective the disposal of waste oil and includes no provisions for the recovery of any of the potential values inherent in the material.

Biodecomposition of oil is accomplished far more effectively by aerobic than by anaerobic organisms. Therefore, appropriate cultivation methods must be employed both to insure that the oil is adequately intermixed with the topsoil layer and that this mixture is sufficiently dispersed (i.e., not compacted) to permit the percolation of air throughout the oily soil. It should be noted that the required intimate contact between the oil and the soil particles may to some degree interfere with oxygen transport to the soil microorganisms.

Fertilization of the soil for the provision of adequate nutritional supplies to the microorganisms increases the rate of the biodegradation process (see Kincannon report cited below). This has been proven as one aspect of experiments conducted by several organizations, including Humble Oil Company, Shell Oil, Marathon Oil and the American Petroleum Institute. An account of biodegradation studies conducted by Shell Oil under the sponsorship of the U. S. Environmental Protection Agency is provided in the project report entitled "Oily



Waste Disposal by Soil Cultivation Process," by C. Buford Kincannon, December 1972 (EPA-R2-72-110). An important finding of these studies was that, without the addition of fertilizer to the soil, the oil decomposition rate was $0.5 \text{ lbs/ft}^3/\text{month}$, under the prevailing climatic conditions of Deer Park, Texas, where these experiments were performed. When fertilizer was used, the rate was about doubled. The depth of soil cultivation and oil/soil intermixing was six inches.

The environmental hazards associated with biodegradation, which may be due to the lead content of the oil, are probably low, provided that the method is employed in areas where the soil is a finely textured clay and where the soil is only slightly acidic, or preferably alkaline; the average pH should be at least six. These factors would tend to inhibit appreciable lead transport through the soil beyond the disposal site area both by reducing its percolation rate and by favoring adsorption of the metal on soil particles.

The likelihood of lead contamination of underlying groundwater should, accordingly, be quite low under such conditions. Rainfall runoff may possibly present a more serious source of environmental concern. For example, in the Shell studies, runoff water analyses indicated oil contents ranging from 30 to 100 ppm. This range greatly exceeds the concentration limit of 15 ppm specified by the Ontario Ministry of the Environment and is therefore unacceptable for discharge into streams or other receiving waters.⁽¹⁾ Furthermore, it is also probable that the oil content of the runoff could exceed concentrations considered acceptable for treatment by municipal wastewater processing



facilities, so that diversion of runoff waters into local sewer systems, if such exist near biodegradation disposal site areas, might be objectionable. For example, the municipal laws of Ottawa set an upper limit to the concentration of oil in discharges to sewers of 100 ppm; those of Windsor provide for no allowable concentration; and those of Toronto specify that materials soluble in petroleum ether (this includes oils and greases) present in discharges to sanitary sewers may not exceed 150 ppm, while discharges to storm sewers are limited to 15 ppm.

An additional problem with waste oil disposal by biodegradation is the large land area required. On the basis of the decomposition rates (assuming no use of fertilizer) and mixing depth reported by Kincannon, an area of about 1200 acres would be required for degradation of one million Imperial gallons of waste oil per month. For most of the year, rates of biodegradation would be much lower in Ontario than in Texas. Hence, larger land areas would be required. Land used for biodegradation would not be available for other, more productive uses.

In view of these considerations, it appears advisable that waste oil disposal by biodegradation be approached with caution. Disposal facilities should include provisions for runoff water collection and treatment to remove most of the oil content prior to its release.

4.1.2 Thermal Destruction

Thermal destruction of waste oil--that is, incineration without useful heat recovery--is open to criticism on two grounds. First, it represents a resource loss for which no compensating benefit is received.



Second, this method inevitably releases pollutant emissions to the air. One Imperial gallon of waste crankcase oil may contain 0.09 pounds of lead. Assuming that half of this is emitted during oil burning, the combustion of a relatively small quantity per day (for example, 1,000 Imperial gallons) could, in the absence of adequate stack particulate emission controls, release 45 pounds of lead to the atmosphere. The matter of ground level lead concentrations resulting from waste crankcase oil burning is addressed in Section 4.2.1, below.

4.2 Waste Oil Use Alternatives

4.2.1 Blending With Fuel Oil

The blending of waste oil with fuel oil for heat content recovery is a fairly well established practice whose attractiveness may now be growing because of the escalating costs of new petroleum stocks and increasing demands for energy. The effect of the combustion of waste oil/fuel oil blends has been investigated in several studies during the past few years. In these studies waste oil/fuel oil blends were burned in steam-electric plant boilers, industrial steam boilers and small home oil burners. Some of the best documented of these test burns are listed below:

<u>Performing Organization</u>	<u>Test Facility</u>	<u>% Waste Oil In Feed</u>	<u>% Lead In Feed Waste Oil</u>	<u>% Lead Emitted (of lead feed rate)</u>
Mobil Oil	Steam boiler	5.0%	1.0%	50%
Shell Oil	Steam boiler	75.0%	0.5%-1.0%	31%
Gulf Oil	Home burner	25.0%	1.1%	28%
Hawaiian Electric Co.	Utility boiler	7.5%	0.45%	25%-29%
Aberdeen Proving Grounds, Edgewood Arsenal	Steam boiler	30.0%	0.67%	3%
Esso Research and Engineering	Steam boiler	100.0%	0.4%-0.6%	less than 50%



These waste oil combustion experiments differ markedly with respect to various factors which influence both operating performance and local ground level lead concentrations. Among these factors are:

Total fuel feed rate	Ranges from 6.25 Imperial gallons/hour to 1,580 Imperial gallons/hour
Soot blowing performed	In two out of the six cases
Type of virgin fuel	#6 in three cases; #2 in two cases
Stack height	Ranges from 15 feet to 137 feet

In addition, the percentages of waste oil incorporated in the fuel tests were in some instances considerably above those anticipated in normal practice. On the basis of these studies and in the light of more extensive routine operating experience, the following broad generalizations can be made:

- The combustion of waste oil/fuel blends has been shown to be technically feasible.
- Where operational problems arise, these are usually traceable to the high metallic content of the waste oil.
- Pre-treatment of the waste oil (before blending) to remove the bottom sediments and water (BS & W) would probably eliminate many of the problems reported. (Clogging effects, feedline freezing in cold weather, and intractable ash deposits in the vicinity of the burner have been noted.)
- The percentage of the lead contained in the waste oil feed that is emitted with the flue gases varies over a considerable range, depending on the extensiveness of heat transfer surfaces and other factors. It is usually less than 50%. However, from an environmentally conservative viewpoint, it is reasonable to assume 50% as a working assumption.

With the exception of the PNAs, the lead emissions to the atmosphere are considered the greatest environmental threat associated with the combustion of waste oil/fuel oil blends. The lead constituent used



in crankcase oils results from combustion of gasoline containing tetraethyl lead and other additives designed to increase octane ratings.

If the costs of waste oil pre-treatment to remove the lead could be significantly offset through recovery of the lead, the procedure might prove operationally as well as environmentally cost-effective. This possibility must, of course, be evaluated in the context of the decreasing use of leaded gasoline, which will attenuate the problem over the long term.

The environmental significance of lead derives from its toxicity, which is compounded by the fact that the metal is stored in bone and is not readily eliminated from the body. Repeated exposures tend, therefore, to be cumulative in their effects. At low dosages--that is, at levels below those associated with overt toxic effects--borderline neurological symptoms may appear, usually taking the form of mild motor disturbances. At higher body concentrations, the consequent physiological effects are more serious and may include damage to kidney function, increased red blood cell fragility with resulting hemolysis, mental retardation in the young, and more profound disturbances of motor function accompanied by sensory impairment. Lead intoxication tends to be chronic and fatal. The significance of lead as a toxic agent far exceeds that of other metals present in waste oil (at the concentration levels at which they occur) and it is for this reason that discussions in the literature of methods of waste oil disposal or use so frequently consider the question of actual or potential releases of lead to the environment.



Under "normal" conditions some small amounts of lead do enter the body by ingestion and by inhalation. Estimates of these amounts have been made, but it is difficult to assess their reliability.

Measurements of the particle size distribution of emitted lead (as well as of other metals) performed during the Esso Research and Engineering waste oil combustion study show that 76% to 79% of the lead fell within a particle size range of less than 1μ , 16% to 21% of the measured particles were within 1μ to 10μ , and less than 4.5% were larger than 10μ . From a health effects viewpoint, the significance of this distribution derives from the prevailing belief that while larger size particles, on inhalation, tend to be expelled from the airways by ciliary action, smaller particles, particularly of submicron dimensions, are more prone to be retained and to reach the alveoli.

Lead emission rates during soot blowing may be greater than those associated with waste oil combustion, as shown by tests conducted by both Shell Oil and Humble Oil and Refining. On the other hand, the sizes of the particles emitted during soot blowing are usually much larger than those released during oil burning, so that, while the ground concentrations of lead during the former operation are higher near the stack, the significant dispersion range may be less.

GCA Technology Division has expressed the opinion that the maximum ground level concentrations of emitted lead can be held to $0.2 \mu\text{g}/\text{m}^3$ for industrial boilers burning waste oil at rates up to 300 Imperial gallons/hour as a blend component.⁴ Further, GCA's calculations for a 560-megawatt power plant with a combustion rate of 25,833 Imperial gallons/



hour show a maximum ground level concentration of lead of $0.15 \mu\text{g}/\text{m}^3$. In these calculations, waste oil was assumed to have a lead content of 1 percent (wt) and to constitute 5 percent of the blend, the balance being No. 6 residual oil. GCA's evaluation suggests that waste crankcase oil combustion should be confined to large industrial and power-generating facilities whose stacks are characteristically high, as opposed to residential and commercial oil burners whose emissions escape via relatively low chimneys which would favor higher ground level lead concentrations. Actual ground level concentrations depend upon stack height, meteorological conditions and terrain slope as well as the rate of lead emissions and the exit gas temperature and velocity. Therefore, in the absence of site specific data, it is difficult to make general statements regarding maximum ground level concentrations of lead resulting from combustion of dilute blends of waste oil in fuel oil.

However, it can be argued from a conservative environmental viewpoint that any addition to the "normal" atmospheric lead burden is inherently objectionable (independently of whatever governmental standards may have been set) and that, therefore, any reduction in lead emissions resulting from waste oil combustion which can be technologically achieved (e.g., pre-treatment for lead removal or use of emissions control devices) is desirable. This position is not dissimilar to that of the U.S. Environmental Protection Agency, which favors reduction of any "presentable" lead emissions.



In a practical sense, the available data support the view that the combustion of waste oil/fuel oil blends, under appropriate conditions, does not present a lead-related threat to health, based on probable maximum ground level concentrations. In terms of total emissions, the combustion of one Imperial gallon of waste oil would release about 0.045 pounds of lead to the atmosphere, assuming that there are no particulate controls and that 50% of the metal escapes with the flue gases. In the case of a facility burning 300 Imperial gallons/hour of blended waste oil, the annual amount consumed would approximate 600,000 Imperial gallons, which would correspond to a total of 27,000 pounds of lead releases. The environmental significance of this in itself is difficult to assess. However, in view of the fact that much of the lead emitted (70%) occurs as submicron size particles with long suspension half-lives, extensive dispersion with consequent dilution would be desirable.

From a conservationist viewpoint, these releases would represent a resource loss of about 13 tons of lead; an examination of the economics of waste oil pre-treatment for lead recovery would be desirable.

The sulfur content of waste crankcase oil is lower than that of fuel oils. Therefore, its use in fuel blends will reduce the emission of sulfur oxides.

4.2.2 Blending With Coal

Probably the best-documented study of waste oil/coal blend combustion was that performed by the Northern States Power Company, Minneapolis, Minnesota, during the latter part of 1973. The blend weight ratio was about 3% oil/97% coal, with a total fuel feed rate of nearly 60,000



pounds per hour. The feed rate of the oil component was, therefore, about 200 Imperial gallons per hour. During the testing period of several days, it was estimated that 24% to 61% of the lead content of the fuel (4.4 ppm (wt) in coal; 3,120 ppm (wt) in oil) was emitted with the flue gases during combustion. The most significant finding emerging from these experiments was that the electrostatic precipitation system, routinely used in the facility, held the lead releases to the atmosphere to less than 1% of the total lead present in the fuel (compared with up to 50%, as conservatively estimated previously for the combustion of waste oil/fuel oil blends). In correspondence from Northern States Power to the American Petroleum Institute regarding these combustion tests, it was stated that the lead release rate was never greater than 0.0071 pounds/hour. This is equivalent to the lead emission rate which would be expected from burning 0.14 Imperial gallons of waste oil in an oil burning type of facility over the same period.

The low levels of lead release experienced in the Northern States Power study are attributable to (a) the relatively high ash content of the coal, which may approximate 10% by weight and (b) the probable adsorption of metal oxide particles on the fly ash surfaces. Electrostatic precipitation is considered to be more effective for particles above 1μ than those below this size. The fly ash particles are considerably larger than most of the PbO particles so that precipitation of the latter would be considerably facilitated by their adsorption on the fly ash.

As noted in Section 4.2.1, neither electrostatic precipitators nor other particulate control devices were employed during the waste oil/



fuel oil blend combustion tests because the oil burning facilities employed are not customarily so equipped. The ash content of residual fuel oil is only about 0.25% (i.e., 1/40th of that of coal).

As the above study obviously suggests, the blending of small amounts of waste oil with coal for fuel use does not present a health hazard, due to atmospheric lead emissions. However, the ultimate fate of the lead adsorbed on the captured fly ash was not addressed in this study.

4.2.3 Waste Oil as a Cement Plant Fuel

The combustion of waste oil in a dry process cement plant was systematically examined in experiments conducted by the St. Lawrence Cement Company, Ltd., during the first half of 1974, with the active collaboration of the Ontario Research Foundation, Environment Canada and several other organizations. A report of this study, entitled "Experimental Burning of Waste Oil as a Fuel in Cement Manufacture," June 1975, was issued by the Environmental Protection Service, Environment Canada (EPS 4-WP-75-1). The two goals of the project were to determine (a) the environmental effects of waste oil combustion as a dry process heat source for the kiln and (b) whether waste oil contaminants would adversely affect product quality.

Under normal conditions, No. 6 fuel oil is fired in the kiln. Reference emissions data were obtained before and after the experiments using this fuel alone. During actual tests, waste oil, having an average lead content of 0.6%, was blended with No. 6 oil. The burn rates of the waste oil component ranged from 22,720 Imperial gallons/hour to 592 Imperial gallons/hour. Material balance analyses showed that most of the lead in the fuel (about 75% to 85%) was ultimately incorporated



within the clinker; about 9% was found in the conditioning tower solids; and about 4% appeared in bypass dust which is collected from the electrostatic precipitator and discarded. Reported stack lead emissions showed a maximum value of about 0.05% of the lead contained in the waste oil. These are extremely small in comparison with the 50% of the fuel lead content which may be released when blends of waste oil and fuel oil are burned in industrial and utility boilers. In absolute terms, the resulting ground level lead concentrations were computed to be less than $0.01 \mu\text{g}/\text{m}^3$, a figure well below Ontario criteria. The corresponding lead uptake rate by inhalation, based on the analysis presented in Section 4.2.1, would be only about $1 \mu\text{g}/\text{day}$. This rate is assessed to have no adverse health implications.

Mass balance studies of bromine, which were also performed, indicated that the emissions of this element to the atmosphere were about 0.7% of the amount introduced in the waste oil. On the assumption that most of the bromine is emitted as KBr, and based on a waste oil bromine content of 0.1%, the ground level concentrations should not have exceeded $0.02 \mu\text{g}/\text{m}^3$. This is only a tiny fraction of the maximum allowable concentration of bromine under Ontario Criteria.²

In order to assess the possible effects of lead content which might impair the quality of the cement produced during waste oil burns, 17 samples were examined. The percentage of lead ranged from 0.0014 to 0.007. The results of various tests applied to the cement (for example, measurements of compressive strength) showed no correlation with lead content and no indication of any correlation with the amount of waste oil burned.



Over all, the use of waste oil as a cement plant fuel appears to be quite attractive. The data suggest that this use alternative induces no deleterious effects on the product and that its environmental impacts of metals and bromine contained in the waste oil are virtually nonexistent. The report also states that cement manufacturing plants are frequently located near populous areas, which should favor the availability of waste crankcase oil supplies.

4.2.4 Used Oil as a Fuel in Municipal Waste Incinerators

This application of waste oil is potentially appealing because it appears to offer a common solution to two significant disposal problems. To date, there have been at least two relatively detailed studies of this application, both of which were addressed primarily to the question of technological feasibility. One of these studies was performed under the sponsorship of the City of Bremerton, Washington and is described in a report entitled "Sewage Sludge Incineration for the City of Bremerton."⁵ The combustion facility used was a fluidized bed incinerator equipped with a water scrubber for the removal of particulate matter from the exhaust gases. The major conclusions were:

- The use of waste crankcase oil as an auxiliary fuel to support sludge combustion was entirely feasible.
- Preheating of the incinerator (by natural gas) to 1,000° F. was necessary prior to burning waste oil in order to prevent clinker formation.
- An atomizing type of nozzle was necessary for satisfactory combustion of the oil.
- Preliminary removal of solids from the waste oil by filtration is recommended.

The report does not provide specific data with respect to emissions. It does include two qualitative statements relating to emissions, as follows:



"Gaseous pollutants emitted from a fluidized bed sludge incinerator are well below the Puget Sound Air Pollution Control Agency's emission standards and thus require no treatment."

" . . . results of size distribution analysis made on exhaust particles suggest that particulate matter can be effectively controlled by a number of methods, including water scrubbing."

In connection with the latter statement, a particulate control system made by the Baker Filtration Company, Los Angeles, California, which combines wet sand filtration and water scrubbing, is said to remove effectively both large particles (over 1μ) and those of submicron size. Test results indicate efficiencies (in terms of particulate retention--i.e., the fraction not emitted) ranging from 85% to 100% for various applications.

A second study conducted by GCA Technology Division for EPA focused on the use of waste oil as a fuel for the combustion of wet refuse.⁶

Three approaches were examined:

1. Direct mixing of the waste oil with the refuse. It was considered that this method posed the possibility of smoke generation.
2. Preheating underfire air. GCA assessment was that this method, though attractive in itself, would probably not provide the total required heat to the refuse bed and that "it would be best applied in conjunction with one of the other specified techniques."
3. Use of auxiliary burners above the refuse bed.

This latter approach was favored and selected for further examination.

GCA concluded that method No. 3 was entirely feasible, provided the conditions of long flame length, high flame temperature (over 2,000° F.) and close spacing of the flame to the refuse surface were maintained in order to assure transfer of sufficient heat flux to the refuse bed. Various burners were investigated, with the result that only atomizing types were found suitable for this application. (This is consistent



with the findings of the Bremerton study summarized above.) Several atomizing burner tests were conducted in which waste oil was burned for eight-hour periods at flow rates ranging from 7.5 to 21 Imperial gallons per hour. Temperatures up to 2,650° were produced. Observers of these tests, including EPA personnel " . . . agreed that from visual inspection the fuel appeared to burn extremely clean. In fact, it was felt that it burned significantly 'cleaner' than comparable residual fuel oils."⁶ No burner plugging was observed during operation.

Actual tests to determine fuel requirements per unit weight of wet refuse were not included in this program but were recommended for inclusion in future studies. However, theoretical calculations were made of these requirements and then multiplied by a factor of 2 to provide a conservative estimate. On this basis, the indicated waste oil fuel requirement is approximately 0.62 Imperial gallons/ton/day of incinerator capacity.

Ground level lead concentration calculations were made for an incinerator burning waste oil. The assumptions included:

- Incinerator capacity of 400 tons/day.
- Waste oil burning rate of 2,250 pounds (about 250 Imperial gallons) per hour.
- Lead content of 1% by weight.
- Lead out/lead in = 50%.
- Stack height of 100 feet.



Calculations based on an eight-hour/day operation for seven days per week showed a three-month (for the winter season) maximum ground level lead concentration of $0.05 \mu\text{g}/\text{m}^3$.

4.2.5 Waste Oil Use in Asphalt Manufacture

The use of waste oil in asphalt manufacture is a fairly well established practice which differs from those previously discussed in that the recovered value is primarily in the form of material rather than of energy. In the United States, for example, the Edgington Oil Company, Long Beach, California, has been processing crankcase drain oil for over twenty years. Process derivatives are used for making asphalt flux and liquid asphalt products. The method employs two steps, as follows:⁷

a. Dehydration

The oil temperature is raised to 200°F . by pumping the oil through a heat exchanger using steam as the heating agent. A demulsifier is added and the mixture is centrifuged. The water and solids are removed from the oil in separate streams. The centrifuge sludge is pumped to a holding tank and skimmed to recover oil on the surface.

b. Distillation

The dehydrated oil is heated to between 600° and 625°F . and passed to the first of two distillation towers. The lighter portion passes to the second tower, where it is refluxed and separated into top (more volatile) and bottom (less volatile) components.



The bottom product of the first tower represents about 55% to 60% of the waste oil feed. Its viscosity is high and, according to Edgington, " . . . is beneficial when blended with asphalt to make a flux for certain oxidized asphalt products." The top product of the second distillation tower is described by Edgington as " . . . a cutter stock low in sulfur, aromatics and olefins content which is used for liquid asphalt products."

The bottom product of the second tower (i.e., the intermediate fraction), has a typical thermal content of 19,500 Btu/lb and is used as a fuel. The metals present in the waste oil after centrifuging are virtually all retained in the first tower bottoms. The asphalt flux, in which this fraction is used, is said not to be impaired by the metal content which, in any case, is quite low. One analysis showed an aggregate metal concentration of less than 20 ppm, with lead accounting for 8.2 ppm.

The method described here, including waste oil processing and the incorporation of processed oil fractions within asphalt or related materials, does not appear to cause any significant releases of either lead or process chemicals. The Edgington method, it should be noted, does not use either sulfuric acid or caustic. Provided that process water is suitably treated prior to discharge, the process should be, on the basis of available information, free of any significant adverse environmental effects.



4.2.6 Waste Oil as a Road Dust Suppressant

The application of waste oil to road surfaces as a dust palliative or suppressant is widely practiced in Canada and the United States.

Although this application is considered by some as environmentally undesirable, there has been surprisingly little research performed which would permit an objective evaluation. Most of the discussions of road oiling in print consist essentially of restatements of the findings and conclusions resulting from a U.S. EPA study conducted by its Edison (N.J.) Water Quality Research Laboratory. An account of this investigation is presented in a report entitled "Run-off from Rural Roads Treated to Suppress Dust," October 1972 (EPA-R2-72-054). The key findings were:

- a. Of the total oil applied to the test road surfaces, about 25%-30% was removed or lost through such mechanisms as adhesion to vehicles, biodegradation and volatilization. About 70% to 75% of the oil left the road surface by rain runoff and dust transport. About 1% remained on the road.
- b. The oil remaining on the road surface was mainly confined to the top one inch.
- c. The oiled road surface contained about 209 mg/kg lead. The lead concentrations reported for the unoiled sections were about 39 mg/kg.
- d. Soil and plant samples in the vicinity of the oiled road surfaces contained lead concentrations which were higher than normal background levels.

Criticisms of this study are not so much addressed to its experimental results as much as they are to implications conveyed by the report to the effect that significant oil runoff is a generic consequence of



road oiling and that the only unresolved question is the magnitude of its ecological significance. Such implications are suggested by report recommendations which state:

"Further study to determine the quantity of waste oils that actually leave the roads should not be undertaken at this time. The fact that the oil leaves the road is clear; precise quantitation is not easily achieved."

"Further study should be undertaken to determine the ecological consequences of runoff oil and its accompanying heavy metals, including lead."

The final recommendation is to the effect that, if "ecological harm" is shown to be a consequence of road oiling, other dust control methods should be defined. Critics of this study who believe general conclusions cannot properly be drawn from its results typically base their position on two elements of the study's experimental design:

1. The test road surfaces were largely clay or of clay-like composition and, therefore, of low porosity. (This would inhibit penetration of oil into the surface, which would obviously favor rain runoff.)
2. The rate at which oil was deposited per unit surface was 0.45 gallons (U.S.) per square yard. (This is about double that used in typical practice. For example, Canam Oil Services, Breslau, Ontario, in its "Special Bulletin," dated February 1973, proposed a "normal" application rate of 0.2 to 0.25 Imperial gallons/yd². If a given area of road surface of a particular porosity can take up or absorb a certain quantity of oil within some time period, the application of an amount of oil substantially above this quantity will leave an excess on the road surface. The presence of this excess amount will increase the ratio of the oil transported by rain-induced runoff to the quantity originally applied.)

Mr. Al Smith, Chief, Environmental Emergency Branch, EPA Regional Office IV, Atlanta, Georgia, has pointed out (private communication to Teknekron) that in road oiling (using waste crankcase oil), as



commonly practiced in certain parts of Mississippi, the oil deposition rate is about 0.17 Imperial gallons per square yard. Many of these oiled roads have an applied "topping" about six to nine inches thick. This topping, which consists of a mixture of alluvial soil and granular clay, is considered to be quite porous. In his own experience, Mr. Smith has seen no evidence of any appreciable runoff from oiled road surfaces of this type. Further, groundwater, which is conscientiously monitored by the State of Mississippi, has been consistently free of lead contamination in the areas in which road oiling was routinely performed.

The limited amount of experimental data available thus far does not provide an adequate basis for formulating general conclusions with respect to the level of environmental hazard that road oiling may present. In fact, a generalized evaluation of this kind may be inherently impossible to support. Accordingly, it is conceptually more realistic to assess this hazard as a function of the particular conditions associated with specific road oiling operations. Such conditions would include the nature of the road surface, character of adjacent soil (pH and porosity), properties of the applied oil and its rate of application (volume per unit road surface area), local topography, precipitation, temperature, and the presence or absence of nearby surface water bodies. In principle, it seems feasible, provided that sufficient information can be acquired, to develop criteria for at least the more important of these factors in order to define those sets of conditions under which road oiling may be performed with relative environmental safety and those under



which the probability of hazard is sufficient to warrant its discouragement or prohibition. The establishment of such criteria would obviously require the undertaking of appropriate experimental studies designed to augment the inadequate existing data base. This approach is directly counter to the position expressed in the Edison Laboratory report which does not recommend that new oil runoff investigations be conducted. However, it is not clear how the second recommendation of this laboratory, namely the further study of the ecological effects of road oiling, can be meaningfully pursued in the absence of more complete information and data regarding runoff and other modes of waste oil transport.

The principal ways in which deposited waste oil and/or its constituent pollutants are believed to be transferred from road surfaces to neighboring sites are:

- By precipitation induced runoff (flotation).
- By airborne transport, possibly in association with dust particles.
- By percolation or migration through soil.

Other mechanisms which may cause oil to leave road surfaces, but which may be of less consistent potential ecological significance, include:

- Direct oil runoff as a consequence of excessive application.
- Volatilization.
- Contact with vehicle tires resulting in adhesion and/or splash.

Runoff due to rainfall may cause waste oil to be transported to nearby streams or other water bodies and to adjacent soil. Obviously, meteorological and topographic factors, as well as the quantity of



residual oil exposed on the road surface, are among the more important factors determining the extent of this effect. Percolation through soil of waste oil and of its contained lead may be expected to occur as a consequence of runoff (and to some degree as a consequence of tire splash). The extent of such percolation will depend, in large measure, on the soil permeability. High permeability, however, may be less a threat with respect to extensive oil diffusion than might appear, because this would also favor the circulation of air through the soil, which would be necessary for the support of aerobic micro-organisms which cause biodegradation of hydrocarbons. Factors which affect lead transport through soil were discussed in Section 3.6.1 of this report. In particular, as was pointed out, heavy metals tend to become adsorbed on soil particle surfaces. The strength of this tendency is characteristically higher at higher pH's. In the case of lead, its adsorption by soils of a pH lower than six is relatively low, but is quite marked for alkaline soils. Independently of this consideration, soil lead is not considered to present a serious threat to groundwater because, except for the northern part of the province, the Ontario overburden consists of impervious clay.

Lead contamination of plant life (including crops) which may occur in the proximity of oiled roads is more apt to be a consequence of exposure to airborne particles of the metal than to result from the absorption of lead in the soil. This view is expressed in a paper on this subject by J. V. Lagerwerff and A. W. Specht of the U.S. Soils Laboratory, U.S. Department of Agriculture, Beltsville, Maryland entitled, "Contamination of Roadside Soil and Vegetation with Cadmium, Nickel,



Lead and Zinc," which appeared in Environmental Science and Technology 4, 583-586 (1970). The authors state that "...it should be noted that, generally, pb is rarely, if at all, taken up by the roots of a variety of plants." (The cited references are: Hammet, F.S., Protoplasma 5, 535-542 (1929); Hevesy, G., Biochem. J. 17, 439-445 (1923); and Marten, G. C. and Hammond, P. B., Agron. J. 58, 553-554 (1966)).

In the Lagerwerff and Specht study, concentrations of lead (and other metals) occurring in or on grass adjacent to various well-traveled highways were measured at distances of 8, 16 and 32 meters from the roads. Metal concentrations were also determined for soil samples at these distances and, for each distance, at depths of 0-5, 5-10, and 10-15 centimeters from the surface. Lead levels in soil at the 0-5 cm depth ranged from 55 to 164 mg/kg (dry) at 32 meters and from 150 to 522 mg/kg at 8 meters for the different test sites. The concentrations of lead associated with the grass were roughly proportional to the observed shallow soil concentrations at the same distance from the roads. It should be noted that the lead concentrations observed in this study originated mainly from the vehicular exhausts and therefore reached the grass and soil via airborne transport. The relatively high concentrations measured reflect the large traffic volumes handled by the thoroughfares in the areas of the test sites. (The numbers of cars passing these sites per 24 hours averaged from 7,500 to 48,000, depending on the particular highway). The observed lead levels are considered to be higher than those which might be expected to occur solely as the result of airborne transport from oiled road surfaces. For example, assume the following:



- o A 100 yard length of road, 7 yards wide, has 0.25 Imperial gallons of waste crankcase oil applied to its surface.
- o The lead content of the oil is 1% (about 0.09 lbs/Imperial gallon).
- o 20% of the lead in the applied oil is subsequently airborne from the road surface and is completely and uniformly deposited, on each side of the road, on two parallel strips of soil, each 32 meters wide.
- o The soil lead content comes wholly from the road oil and from no other source.

Under these admittedly artificial assumptions, the resulting concentration of lead on the soil surface would be 2.6 mg per square decimeter. If it is assumed that all of the lead diffuses uniformly to a depth of 5 cm and that the dry density is 3, the resulting concentration of the metal in the soil would be 1.7 mg/kg. In order to arrive at a rough estimate of the equivalent concentration in vegetation, the data presented in the Lagerwerff and Specht paper were analyzed in terms of the ratios of the measured lead concentrations in grass (mg/kg) to those found in the 0-5 cm soil layers at the various test sites. For each test site, the arithmetic means of the concentrations reported in grass and soil (for the 0-5 cm depth) at the 8, 16 and 32 meter distances from the road were determined. The ratios of these means (grass concentration in mg/kg divided by the soil concentration in mg/kg) ranged, for the different test sites, from a low of 0.09 to a high of 0.21. The high value was taken as a "worst case." Using this as a factor, the inferred lead concentration in vegetation (for the hypothesized road oiling example) was computed to be 357 μ g/kg. This is roughly 1/21 of the lowest concentration of lead reported by the above authors as a consequence of airborne transport of vehicular lead emissions.



It will be noted that the calculated lead concentration in vegetation is considerably lower than that reported in the EPA Edison Laboratory road oiling study. According to the latter, "...plant samples...showed an average lead concentration of 33.5 mg/kg which is higher than the expected background level." (These samples were collected from a point 150 feet from the road.) The EPA report does not, however, indicate how much higher the measured concentrations were than the "expected" levels. The significance of this point lies in the fact that it is precisely the increment over the background (which may be due to vehicular exhaust or other emission sources) that is, presumably, attributable to lead transport from oiled roads. If, in the hypothetical example, it had been assumed that all of the lead in the deposited oil were transported to the soil (instead of only 20%) and that the oil application rate had been 0.45 IG/yd² (approximately the rate used in the Edison Laboratory study) instead of 0.25 IG/yd², the resulting concentration of the metal in the plants would have been 3.2 mg/kg (dry). If this value is assumed for the EPA experiment, the equivalent background concentration would have been equal to

$$33.5 \text{ mg/kg} - 3.2 \text{ mg/kg} = 30.3 \text{ mg/kg}$$

Thus, the increment (attributable to road oiling) above background would have been approximately 10%.

Although the preceding analysis is, of necessity, speculative, it does strongly suggest that road oiling may be only a minor contributor to the lead concentrations observed in neighboring plants, with the preponderant portion of these caused by other sources of lead. In any case, however, the possibility of lead deposition on grass or other plant life which may be used for forage raises the question of the



potential threat to cattle. The available data are sparse, but suggest that some measure of lead tolerance exists. For example, calves who consumed up to 2.0 grams of lead per day have been known to survive from 2 to 3 years. Higher dosages of 0.2 to 0.4 grams per kilo body weight, however, appeared to be fatal within relatively short periods (a few days).*

In terms of human tolerance for lead, there is a considerable range of estimates and experience. It is believed that the intake rate at which excretion can exceed accumulation is probably not over 1.0 mg/day, although this does not imply that this rate may not be toxic. For example, chronic lead ingestion of 0.1 mg daily over several years has been reported to cause lead poisoning, and one authority considers an intake rate of 0.2 mg/day to be unsafe. Another authority, however, believes that a rate of 0.5 mg/day is "safe," and an instance is known in which a daily intake of 2.0 mg for a year did not appear to impair health.*

The possible contamination of inland surface water bodies due to waste oil runoff is another matter for concern. A study of the implications of such contamination for biota was conducted at the U.S. National Water Quality Laboratory, Duluth, Minnesota and described in a report entitled, "The Effects of Waste Oil on Freshwater Aquatic Life," S. F. Hedtke et al., U. S. EPA Waste Oil Study (Report to Congress), Appendix C, April 1974. Using water soluble extracts at various concentrations, as well as other methods of oil introduction, acute

* These figures are cited on page 206 of "Water Quality Criteria," Second Edition, California State Water Resources Control Board, Publication No. 3-A, Revised 1963.



mortality tests were performed on the flagfish (Jordanelia floridae) and the fathead minnow (Pimephales promelas). In addition, chronic toxicity tests were conducted (on Jordanelia) based on such criteria as egg hatchability and the survival and growth of fry. Lethal oil concentrations (for different species and methods of oil introduction) ranged from 0.1% to 1.1% (vol). The chronic "no effect" concentration for the water soluble oil fraction ranged from 0.08% to 0.33% (vol), corresponding to a range of 80 $\mu\text{l/l}$ to 330 $\mu\text{l/l}$ for the total oil. The authors considered that this level applied to the oil, but not to its lead content, and that "...the chemical characterization of the waste oil indicates the potential for damage due to lead at less than 8 $\mu\text{l/l}$ total oil." (This conclusion is apparently based on the concentration of lead in the waste oil used in this study, which was 18,500 $\mu\text{g/g}$.)

With respect to the toxicity of lead for aquatic life, the data suggest that many organisms may be susceptible to the effects of this metal, even at quite low concentrations. Several citations to this effect appear in a report prepared by the National Academy of Sciences (NAS), under the sponsorship of the U. S. EPA entitled "Water Quality Criteria in 1972." (The report was issued as EPA R-73-033, March 1973, although it is believed to have been first printed in 1975.) For example, the growth of guppies has been reported to be affected by lead concentrations of 1.24 mg/l and chronic effects on sticklebacks have been observed at levels of 0.1 and 0.3 mg/l. The induction of chronic lead toxicity in daphnia as well as effects on reproduction have been cited for concentrations as low as 0.03 mg/l. The NAS



report recommends that "the concentration of lead in water should not be higher than 0.03 mg/l at any time or place in order to protect aquatic life." This recommendation suggests that the Ontario water quality criterion for surface water lead content of 0.05 mg/l is not overly stringent.

In terms of the overall question of lead toxicity to fish, it must be understood that it is difficult to make categorical statements for two reasons. The first is that there appear to be significant differences among the susceptibilities of various species; the second, and of greater importance, is the fact that the carbonate level in the water containing the lead has a great effect on the toxicity of the metal (to fish).

In hard water containing a relatively high concentration of CaCO_3 , dissolved lead tends to be precipitated as lead carbonate. (Lead is about 167 times more soluble in soft than in hard water.) It has been well established that lead present in soft water is far more toxic to fish than lead present in hard water. For example, the NAS report cites 96-hour LC50 soft water concentrations of lead (for the fathead minnow and brook trout) as 5-7 mg/l and 4-5 mg/l respectively. For hard water, the equivalent values are 482 mg/l and 442 mg/l. (The 96-hour LC50 concentration is that concentration which kills 50% of the exposed test sample within the stated period. This is a measure of acute, rather than chronic, toxicity.) Chronic studies of lead toxicity in soft water suggest that adverse effects may occur at fairly low levels. Exposures of rainbow and brook trout for 2 to 3 months to lead concentrations of 0.1 mg/l (in soft water) "indicated



detrimental effects" (NAS report). The same report cites adverse effects on the conditioned behavior of goldfish at a concentration of 0.07 mg/l (also in soft water).

It is not clear that the difference of solubility of lead in hard versus soft water is the whole explanation for the difference observed in the corresponding toxicity levels. For example, according to "Water Quality Criteria," a publication of the California State Water Resources Control Board, it is stated that "in soft water, lead may be very toxic; in hard water equivalent concentrations of lead are less toxic..." (emphasis ours). Also, "calcium in a concentration of 50 mg/l has destroyed the toxic effect of 1.0 mg/l of lead" (page 207). This document recommends that "...the dissolved lead content of surface waters should be restricted to 0.1 mg/l..." The text also alludes to the hazard presented stock and wildlife watering sources contaminated by lead. The point is made that "it is not unusual for cattle to be poisoned by lead in water; the lead need not necessarily be in solution, but may be in suspension, as, for example, the oxycarbonate." Also, "chronic lead poisoning has been caused by 0.18 mg/l of lead in soft water."

The current Ontario water quality criteria for lead and oil/grease are probably sufficiently rigorous to afford adequate protection from these pollutants to biota in inland surface waters, provided, of course, that the criteria are enforced. However, the oil/grease limit of "virtually absent" could be difficult to administer unless supplemented



by some more quantifiable criterion, such as a defined fraction of the 96-hour LC50 for some particularly sensitive aquatic organism. With respect to airborne lead transport from oiled roads to adjacent land there does not appear to exist a directly applicable criterion. However, paragraph 5 under Part II of the Ontario Environmental Protection Act, 1971 (Statutes of Ontario, 1971, Chapter 86 as amended) states that "no person shall deposit in or add to, emit or discharge into the natural environment any contaminant, and no person responsible for a source of contaminant shall permit the addition to, emission or discharge into the natural environment of any contaminant from the source of contaminant, in an amount, concentration or level in excess of that prescribed by the regulations." It is true that Ontario Regulation 872/74 which was established (1974) under the cited act does specify ambient air quality criteria for lead ($5.0 \mu\text{g}/24$ hours; $2.0 \mu\text{g}$ - geometric mean for 30 days). It would, however, probably prove difficult to apply these criteria in the oiled road context because much of the monitored ambient lead concentrations would be caused by vehicular exhausts. It would be virtually impossible to identify the airborne lead component specifically attributable to road oiling.

In view of the fact that the level of environmental hazard presented by road oiling may vary substantially with the particular conditions and circumstances, it is recommended that consideration be given to the implementation of a controlled study. This study would be sufficiently comprehensive to permit the formulation of standards and criteria which would permit an assessment to be made of the environmental impact of any specific road oiling activity.



At the outset, criteria should be established for the character or quality of the oil to be deposited. For example, we have been informed that there is reason to believe that in one case, at least, acid sludge may have been employed as a dust suppressant agent. This application should obviously be prohibited. Further requirements should be formulated with respect to the manner of waste oil collection and storage. Such requirements should be designed to protect the oil from accidental or deliberate contamination with highly toxic materials, particularly those which are hazardous in even very low concentrations.

Experimental designs which would contribute to more complete assessments of the effects of road oiling under different conditions should, in order to provide a common reference framework for proper evaluation of the results, all be based on a standardized application rate, such as 0.25 IG oil per square yard. There may also be some advantage in using a single oil sample of adequate amount for all the test studies. This sample should be typical of the waste oil most commonly used in practice and should be of reasonably well known composition. For example, a rough characterization of the oil in terms of constituents would include determination of the percentages of volatile oil soluble and oil insoluble substances present. The lead content should, of course, be measured. Physical characteristics of the oil to be quantified should include a few key parameters such as specific gravity, viscosity index and flash point. There is a moot question as to whether the oil should be subjected to any pre-treatment, such as settling and filtration, prior to its analysis and application in the test studies. For example, filtration might prove beneficial in removing any coarse lead or lead containing



particles, as well as those of other metals. However, since the purpose of the program is that of setting criteria which would apply to commercial road oiling practice, pre-treatment, if used in the experiments, should then, in our view, be subsequently required of road oiling firms.

The experimental designs should be oriented to the evaluation of road oiling effects as consequences of the various factors which may cause or influence these effects. These factors can, in general, be broadly categorized as follows:

- Factors affecting retention of deposited oil. These would include:
 - a. Deposition rate (which is presumed to be uniform).
 - b. Temperature (as this affects oil viscosity).
 - c. Porosity of road surface.
 - d. Road surface geometry (crown).
 - e. Precipitation.
- Factors affecting transport:
 - a. Precipitation.
 - b. Adjacent soil porosity, erosion.
 - c. Adjacent soil pH.
 - d. Winds.
 - e. Proximity of streams.

With respect to the evaluation of the magnitude of lead transport from the road surfaces to plant and soil in the neighborhood of the test areas, it is expected that two problem areas may be encountered:



- a. Distinguishing between lead concentrations due to road oiling and those caused by vehicular exhausts
- b. Distinguishing between lead concentrations due to airborne transport and those caused by percolation through the soil

With respect to the first, it is suggested that some test road surfaces be constructed in areas remote from vehicular traffic and in which background lead concentrations in soil and plants are sufficiently low so that any incremental effects due to oiling the test surfaces could be unequivocally determined. With respect to the second, it is recommended that selected areas of the soil neighboring the test sites be initially covered in order to substantially attenuate, if not actually prevent, the deposition of airborne lead. If, for example, the differences between the incremental lead concentrations (with respect to the previously determined background levels) are large for the uncovered areas, but small for the covered areas, this would obviously suggest that airborne transport (as opposed to percolation or diffusion through the soil) was the major factor.

It is recognized that an experimental program of the kind suggested here may, if properly designed and effectively executed, prove relatively costly. Its results should, however, replace any prevalent, purely attitudinal orientations toward road oiling with an understanding and assessment capability based on sound experimental data. In particular, it should make possible the formulation of criteria and guideline rules which would provide a firm basis for such pronouncements. For example, for a given category of road surface (e.g., impervious clay), road oiling with waste oil in the vicinity of agricultural or crop land is potentially



hazardous and is either strongly discouraged or prohibited; it may be permissible in other locational settings. In the case of roads with relatively thick and quite porous toppings, the constraints may be less severe. In any case, it is unlikely that any extreme position toward road oiling as a whole, whether uncritical permissiveness or total opposition, will be found fully warranted by the results of the proposed experimental program.

4.2.7 Blending with Diesel Fuel

This discussion differs from those preceding it in that it addresses uses of waste oil from vehicles equipped with diesel engines rather than waste oil from vehicles equipped with gasoline engines.

This application is discussed in a brochure issued by the Chevron Oil Company, 1975, entitled "Used Crankcase Oil--If You Can't Recycle It, Why Not Burn It in the Engine?" This publication reviews the comments and recommendations, both pro and con, of a number of diesel engine manufacturers, including Allis-Chalmers (recommends against), Caterpillar Tractor Company (provides guidance for this application), Detroit Diesel Allison Division of General Motors (recommends against), International Harvester Construction Equipment (provides guidance for the application; the Agricultural and Industrial Division recommends against) and the Cummins Engine Company (provides guidance). In general, the manufacturers who recommend this application, or at least provide guidance for implementing it, stress the importance of thorough mixing of the waste oil with the diesel fuel in order to avoid fuel system filter plugging, unsatisfactory combustion and other deleterious effects.



The recommended percentages of waste oil in the blend are low in all cases. The usual recommended range is from 2% to 5%; the highest recommended percentage is 6.5%. The only pre-treatment suggested is filtration in order to remove gross particulate content.

This application should be relatively bland in environmental terms because of the absence of lead in the waste oil.

4.3 Comparative Summary of Alternative Technologies

This discussion focuses on the beneficial waste oil uses.

4.3.1 Fuel Applications

These applications include blending with oil, blending with coal, use in cement manufacture and use in municipal incinerator facilities. In all methods for waste crankcase oil use as a fuel, the lead content has been considered as a key environmental threat. In all of these fuel uses, the lead is virtually completely volatilized, thus posing the likelihood of its emission to the atmosphere. In this specific context, the major difference among alternatives is the degree to which lead may be released in the various combustion modes. Therefore, the key question is whether this degree may be sufficient to generate ambient concentrations that represent hazards to health.

Of the various technologies considered, blending with oil for use in industrial facilities and direct fuel use in municipal incinerators appear to generate the highest net emission rates. Precise evaluation is difficult because these levels in some cases reflect



actual measurements and, in others, computations. In principle, it would not be expected that commercial oil burning facilities would be equipped with particulate emission control systems, but this is not necessarily the case for municipal incinerators. As suggested, water scrubbers may be quite effective in reducing small particle (less than 1 μ) emissions.. This implies the likelihood that of the two methods, combustion of waste oil in incinerators may be preferred over the long run.

The burning of waste oil/coal blends under the reported conditions presents virtually no potential for generating significant ground level concentrations of lead. The ratio of lead emitted to the lead content of the oil burned was estimated to be 1% for the Northern States Power test burns. This low ratio is not a consequence of the combustion process but rather a result of the fact that coal burning facilities are customarily equipped with precipitators which effectively suppress the emissions of PbO particles, since these are largely absorbed of fly ash surfaces. The overall implication is that waste oil can be burned with comparative safety (in the sense that there is no significant environmental threat due to lead emissions) in utility and probably industrial coal combustion facilities, with no need for additional capital investment.

The use of waste oil as a cement plant fuel is particularly attractive in terms of resource use. As shown by the St. Lawrence experiments, most of the lead contained in the waste oil becomes incorporated in the clinker and in the conditioning tower solids. Further, the effectiveness of the electrostatic precipitators (with respect to lead removal from the flue gas) suggests that most of this lead may have been absorbed



on the surfaces of larger particles in a manner analogous to that believed true for the waste oil/coal blend combustion case.

4.3.2 Use of Waste Oil in Asphalt Manufacture

This application, at least as performed by Edgington, is appealing from an environmental standpoint because virtually all of the waste oil heavy metal contaminants, including lead, should remain in the distillation bottoms and these, in turn, become incorporated in the final product. Thus, lead emissions to the atmosphere should be essentially nil.

4.3.3 Road Oiling

As indicated in the discussion in Section 4.2.6, the environmental hazards which are, or may be, associated with this alternative are virtually impossible to assess except in the context of the specific conditions under which it is employed. Under some, it may be environmentally safe. Under other conditions which could favor extensive runoff, there could be a potential threat to local biota. In neither case does there seem to be any real hazard to groundwater.

4.3.4 Blending With Diesel Fuel

As stated in Section 4.2.7, the used oils considered under this topical heading are diesel crankcase oils which contain essentially no lead. Therefore, the concern is not of an environmental nature but rather with acceptance by engine manufacturers and operators.

4.4 Environmental Implications of Waste Oil PNA Content

Polynuclear aromatics (PNAs) occur in waste oil and are relevant in the context of this report because of their carcinogenic potentialities. PNA releases were not considered in any of the studies cited in this chapter. Therefore, in view of the absence of pertinent PNA data relating to specific waste oil applications, the topic is addressed as an overview of all applications.



PNA and polar compounds occur in both virgin and used automotive crankcase oils, but at somewhat higher levels in the latter. The sometimes cited figures which indicate that this increase is about 25% (4.9% in waste oil, as compared to 3.9% in virgin lube oil) appear in a report issued by the Bartlesville Energy Research Center, Bureau of Mines, U.S. Department of the Interior (Report of Investigations 7884, entitled "Waste Lubricating Oil Research: An Investigation of Several Re-refining Methods," 1974). These data, however, reflect findings for two samples only and, accordingly, caution should be employed in their use. There is, however, no doubt that significant increases in the concentrations of some specific PNAs in automobile crankcase oil can occur. In particular, it has been shown that the concentration of benzo-a-pyrene (BaP) in virgin lube oil may increase by a factor approximating 20/1, the degree of increase depending on the amount of BaP in the gasoline and, of course, on the length of oil service between changes. In terms of absolute values, concentrations up to 16 ppm of BaP in used oil have been observed (compared with 0.7 ppm for virgin oil). A recent paper by C. Thony, et al. ("Concentrations en Hydrocarbures Polycycliques Aromatiques Cancérogènes de Quelques Huiles Minérales," Archives des Maladies Professionnelles, de Médecine et de Sécurité Sociale (Paris), 1975, 36, no.1-2, Janvier-Février, pp 37-62), presents data showing that the BaP concentration in motor lube oil may increase by a factor as high as 100/1.

The carcinogenicity of mineral oils has been recognized for many years, including that of oils known to be BaP-free, but which may contain other PNAs, such as di-, tri- and tetramethyl naphthalenes and phenanthrenes,



chrysene and its methyl derivatives, perylene, triphenylene and tetramethylfluorene. Identified heterocyclic carcinogens found in mineral oils include di- and tetramethyldibenzothiophenes, thiobenzofluorene and tetra- and pentamethylcarbazoles. Routine handling of many mineral oil varieties can be hazardous. The medical literature implicating exposure to mineral oil as a cause of cancer abounds with references dating back to 1875.

The carcinogenicity of mineral oil tends to increase as its temperature is raised, possibly in consequence of cracking which forms new compounds. Generally speaking, PNAs are usually associated with the higher boiling point fractions (i.e., over 350°), but carcinogens have been found in more volatile fractions also. As a whole, the evidence does suggest that the PNA content of automobile crankcase oil could increase with its continued use, independently of the BaP taken up from the fuel.

As a whole, PNAs are relatively heat resistant, requiring fairly long exposures to temperatures of the order of 3,000° F. for their effective thermal destruction. Such temperatures are above those typical of fuel burns and it may therefore be assumed that in most waste oil combustion processes a considerable fraction of its PNA content escapes to the atmosphere. Thus, it is highly probable that burning waste oil will cause PNA releases. The significance of such releases as a threat to human health is, however, far from clear. This is true for several reasons:

- a. There appears to be a total absence of information, whether based on actual measurements or on calculations, which provides any indication of the ground level PNA concentrations which occur, or which may be expected, in consequence of waste oil combustion under



any conditions. A value for BaP of 1mg/m^3 has been reported for domestic stack effluents arising from coal combustion. The range of ambient urban concentrations of this PNA, as reported for various cities and seasons, is enormous, ranging from 0.03ug/1,000m^3 to 2.2mg/m^3 in an extreme case. Concentrations up to 100ug/1,000m^3 are more typical. In general, winter levels are higher than summer levels, possibly because of greater amount of fuels consumed. Urban levels are considerably higher than rural levels, by a factor of about 100.⁽⁸⁾

- b. There appears to be a total absence of data relating the magnitude of human carcinogenic risk to both period of exposure and ambient concentration. There have been animal inhalation studies designed to assess the carcinogenicity of the agent being tested, but these usually employed far higher concentrations of the PNA than might be expected to occur under realistic conditions. For example, in one series of experiments, rats were exposed to air containing a mixture of 10mg/m^3 BaP + 3.5 ppm SO_2 (SO_2 is considered to have a synergistic effect in PNA-induced carcinogenesis).⁽⁸⁾ In another set of experiments, designed to assess the carcinogenicity of 1,2,5,6 -dibenzanthracene (an automobile exhaust constituent), 170 rats received direct intratracheal doses of 0, 0.5, 2.0, 10 or 20 mg. In contrast, observed ambient urban concentrations (in German cities) ranged from 3.2ug to 32ug/1,000m^3 .

The problem of defining ambient PNA concentrations in terms of carcinogenic risk is further complicated by the magnitude of the role that synergistic effects may play in this relationship. (SO_2 has already been mentioned in this connection.) For example, in PNA skin painting experiments with mice, it has been found that the simultaneous application of dodecane greatly augments the carcinogenicity of the PNA. For benz-a-anthracene this factor is about 100; for BaP it is about 1,000.⁽⁸⁾

- c. The few available discussions of waste oil PNA content which were reviewed during this study consider this question wholly on the basis of the augmentation of the original virgin lube oil PNA concentration. The question of how the concentrations of PNAs normally present in fuel oil compare with those found in waste crankcase oil has not been examined, although it clearly is of considerable importance, with particular reference to the combustion of waste oil/fuel oil blends. The issue is whether effluent PNAs originating from the waste oil are or are not likely to augment the PNA releases attributable to the fuel oil alone.

Under the sponsorship of the American Petroleum Institute, Esso Research and Engineering Company analyzed samples of



various oils which the Institute had identified for investigative use in certain of its programs.⁽⁹⁾ Analyses of No. 2 fuel oil showed a total aromatic content of 38.2% by weight. Of this, acenaphthenes (identified carcinogens) and naphthalenes (many of which are carcinogenic) accounted for 9.7%. Bunker "C" oil was found to contain 34.2% total aromatics. These included acenaphthenes, naphthalenes and phenanthrenes (many of which are known carcinogens), which accounted, in aggregate, for 17.3% of the total aromatic content. These data suggest that the percentages of known or suspect carcinogens present in common fuel oils may exceed those likely to exist in waste automotive oil. The significance of this may be augmented by the fact that the waste oil fraction of waste oil/fuel oil blends is relatively small. For example, assuming a waste oil PNA content of 5% and a fuel oil PNA content of 9%, the combustion of the fuel oil only would result in the emission of 0.81 pounds of PNAs per Imperial gallon. For a blend containing 10% of waste oil, the corresponding PNA emission would be approximately 0.78 pounds. In terms of total quantity of PNAs emitted per Imperial gallon of oil burned, it would appear that the releases could actually be less for blends than for straight fuel oil. (It was assumed that 100% of the PNAs in the oils are emitted.) From a health effects viewpoint, the combustion of waste oil/fuel oil might seem more appealing than the burning of straight fuel oils. This conclusion, however, could well be incorrect because it does not take into account the relative carcinogenicities of the emitted PNAs which have not yet been evaluated.

In view of the considerations presented above, it is not considered possible at this time to develop a meaningful assessment of the risks to health which may be attributable to emissions of PNAs from the combustion of used crankcase oils.



CHAPTER FOUR

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5. "Sewage Sludge Incineration for the City of Bremerton"; Chin, Mayo and Company; Seattle, Washington; September 1973.
6. "Waste Automotive Lubricating Oil as a Municipal Incinerator Fuel"; EPA Report EPA-R2-79-293; Prepared by GCA Corporation; September 1973.
7. Communication from Robert A. Hall, Edgington Oil Company to American Petroleum Institute; July 1973.
8. IARC Monographs on the Evaluation of Carcinogenic Risk of the Chemical to Man, Volume III: Certain Polycyclic Aromatic Hydrocarbons and Heterocyclic Compounds; International Agency for Research on Cancer; World Health Organization (1973).
9. Pancirous, R.J.; "Compositional Data on API Reference Oils Used in Biological Studies"; Report No. AID.1BA.74.; Esso Research and Engineering Company; Analytical and Information Division; Linden, New Jersey; February 1974.



5. DEMAND FOR LUBRICATING OIL IN ONTARIO

5.1 Introduction

The future demand for re-refined lube oil in Ontario will be determined largely by the net effect of two factors: (1) the acceptance of re-refined oil as a substitute for virgin base lube stocks, and (2) the overall supply/demand balance of base lube stocks. Historically, only minor efforts have been made to produce high grade re-refined base lube stocks on a provincial or national scale or to encourage the use of re-refined oil by demonstration projects or government regulations. Nor has there been a major marketing effort to reach the major users. Consequently, past sales data do not provide a useful guide to acceptance of re-refined products. Survey data on consumer attitudes shed some light on acceptance. This subject is discussed in some detail in Chapter 6.

This chapter is devoted to a forecast of the overall demand for lube oils in Ontario and an analysis of lube oil supply. The supply assessment is based upon announced expansion plans of major refiners and historical patterns of provincial production, inter-provincial transfers, and imports.

The demand for lube oils has two major components: automotive and industrial. Automotive demand is determined primarily by vehicle miles traveled and average oil consumption per vehicle mile. Industrial demand is determined primarily by the level of industrial activity.

Table 5.1, based upon Statistics Canada data, shows historical figures for lube oil sales in Ontario disaggregated by end use. The classification does not, however, coincide with the desired detailed division



TABLE 5.1

LUBE OIL SALES IN ONTARIO

(Units: Barrels of 35 Canadian Gallons)

Years	Retail Pump Outlets	Farms	Railways	Federal and Provincial Governments	Marine	Other*
1963	452,865	38,333	39,176	N/A	6,567	795,053
1964	416,011	62,721	41,111	110,645	7,018	716,785
1965	460,183	60,285	51,408	98,663	7,243	827,363
1966	424,782	58,745	41,580	85,428	10,832	1,188,267
1967	420,092	56,317	43,786	76,256	10,955	1,131,762
1968	407,856	61,473	43,255	67,704	11,895	1,184,109
1969	384,896	66,185	49,188	60,584	14,727	1,328,258
1970	397,559	86,796	61,816	48,942	13,855	1,259,854
1971	405,953	68,639	85,402	54,426	11,082	1,342,108
1972	447,922	71,235	86,214	61,361	13,677	1,410,831
1973	403,622	80,386	74,383	44,568	16,870	1,861,374

*For some years, a further breakdown of this category is given. However, the breakdown is not consistent during the period covered by the table.

Source: "Refined Petroleum Products", Publication 45-208, Statistics Canada, Ottawa.



of demand needed in this study.

A second and more useful source of historical data on sales by type of oil was obtained from a survey of major oil companies conducted with the assistance of the Ministry of Energy. Responses were received from British Petroleum, Gulf, Imperial, Petrofina Canada, Shell, Sun and Texaco. These companies supply a very large fraction of lube oil demand in Canada. Table 5.2 provides estimates of the proportion of total lube oil sales in Ontario which are supplied by these companies.

The sales by major category of oil use by major oil companies is given in Table 5.3. A comparison of Tables 5.1 and 5.3 reveals that the ratio of retail sales in Ontario to the reported automotive oil sales of major suppliers has remained relatively stationary, with values of 0.437, 0.436, 0.482 and 0.404 in 1970 through 1973. However, since the percentages in Table 5.2 appear to include undetected, inter-provincial transfers, it did not appear desirable to attempt to use proportions to inflate retail sales to total demand for automotive oils. We have chosen, therefore, to forecast a separate demand for retail sales, subsuming the remainder of automotive oil sales under industrial demand.

Throughout this analysis, we have encountered inconsistent data reporting in the lubricating oil industry, combined with an absence of data necessary to maintain adequate accounts by end use. Further, the major explanatory variables, such as real domestic product in Ontario, are themselves not effectively forecasted and do not take into account the economic conditions in the 1974-1975 period. The demand forecasts represent assessments based on the best available data. However, care should be used in

TABLE 5.2
PROPORTION OF TOTAL LUBE OIL SALES IN ONTARIO
COVERED BY QUESTIONNAIRE RESPONDENTS,* BY YEAR

<u>Year</u>	<u>Percent**</u>
1969	88
1970	104
1971	99
1972	97
1973	86

* In the survey on sales by type of oil

**The percentage may exceed 100 because of sales of oils for resale to ultimate consumers outside Ontario.



TABLE 5.3

ONTARIO LUBE OIL & GREASE SALES BY TYPE OF LUBRICANT
(In 1000 Barrels of 35 Canadian Gallons)

	<u>1969*</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>
<u>Oils</u>						
Automotive						
Crankcase Oils	612.48	754.62	760.79	765.73	819.48	813.68
Hydraulic Oils	116.57	114.54	130.31	122.22	118.82	138.54
Gear Oils	34.85	39.37	39.40	40.76	45.97	45.06
Miscellaneous	<u>N/A</u>	<u>.65</u>	<u>.80</u>	<u>1.11</u>	<u>1.43</u>	<u>1.43</u>
	<u>763.90</u>	<u>909.18</u>	<u>931.30</u>	<u>929.86</u>	<u>985.70</u>	<u>998.71</u>
Industrial						
Engine Oils	53.91	68.05	80.80	84.71	79.37	81.91
Hydraulic Oils	266.85	307.37	315.79	400.23	348.05	375.00
Gear Oils	39.91	44.99	46.51	42.59	42.65	46.31
Metalworking Oils	60.22	97.99	65.71	72.77	80.71	72.37
Process Oils	354.31	360.97	348.20	351.63	397.08	426.94
Miscellaneous	<u>141.28</u>	<u>147.17</u>	<u>157.11</u>	<u>165.00</u>	<u>195.45</u>	<u>191.00</u>
	<u>916.48</u>	<u>1026.54</u>	<u>1014.12</u>	<u>1116.73</u>	<u>1143.31</u>	<u>1193.53</u>
Total Oils:	1680.38	1935.72	1945.42	2046.79	2129.01	2192.24
<u>Greases</u>						
Automotive	18.14	20.88	23.68	23.62	26.19	21.77
Industrial	<u>32.74</u>	<u>38.60</u>	<u>35.31</u>	<u>29.23</u>	<u>30.63</u>	<u>29.91</u>
	<u>50.88</u>	<u>59.48</u>	<u>58.99</u>	<u>52.85</u>	<u>56.81</u>	<u>51.68</u>

*One of the seven respondents did not submit a report for 1969.

Source: Company Reports, Ministry of Energy Survey



drawing conclusions from these forecasts for purposes other than those intended in this study.

5.2 Retail Sales

Retail pump outlet sales of lubricating oils in Ontario are shown in Table 5.4 and graphed in Figure 5.1. These data show little historical trend. The trend rate of growth, estimated from the regression

$$\log (\text{Retail Sales}) = a + b (\text{year})$$

yields the estimates $a = 6.576$ ($SE = .345$) and $b = -.008$ ($SE = .005$). The trend rate of change, -0.8 percent, is downward, but small in magnitude. The retail sales are mostly sales of automotive oils. Oil consumption in motor vehicles depends on two primary factors, vehicle miles traveled (VMT) and average oil consumption per vehicle-mile. Each of these factors will be examined in turn. Since retail sales are primarily to passenger automobiles, we confine our attention to these vehicles.

5.2.1 Vehicle Miles Traveled

Estimates of VMT were based on the number of vehicles in operation and average annual mileage per vehicle. Consider first the number of vehicles. Table 5.5 shows the number of passenger vehicle registrations in Ontario, the provincial population, and the vehicle per person ratio in selected years. The ratio of persons to vehicles dropped from 3.3 in 1963 to 2.6 in 1973. Fitting a linear trend to the inverse ratio of vehicles per person provides an exceptionally good historical presentation. Figure 5.2 shows actual and projected registrations derived from the five and ten year linear trends. Table 5.6 gives projections based on these trends and on Statistics Canada projections of population for Ontario. The five year trend implies an average growth rate for number of vehicles per person



Table 5.4

SALES OF LUBRICATING OILS AT (RETAIL) SERVICE STATIONS

(Units: 1000 Barrels of 35 Canadian Gallons)

<u>Year</u>	<u>Sales at Retail Outlets</u>	<u>Year</u>	<u>Sales at Retail Outlets</u>
1963	453	1969	385
1964	416	1970	398
1965	460	1971	406
1966	425	1972	448
1967	420	1973	404
1968	408		

Source: Publication 45-208, "Refined Petroleum Products,"
Statistics Canada.



Figure 5.1

Sales of Lubricating Oils at Retail Pump Outlets

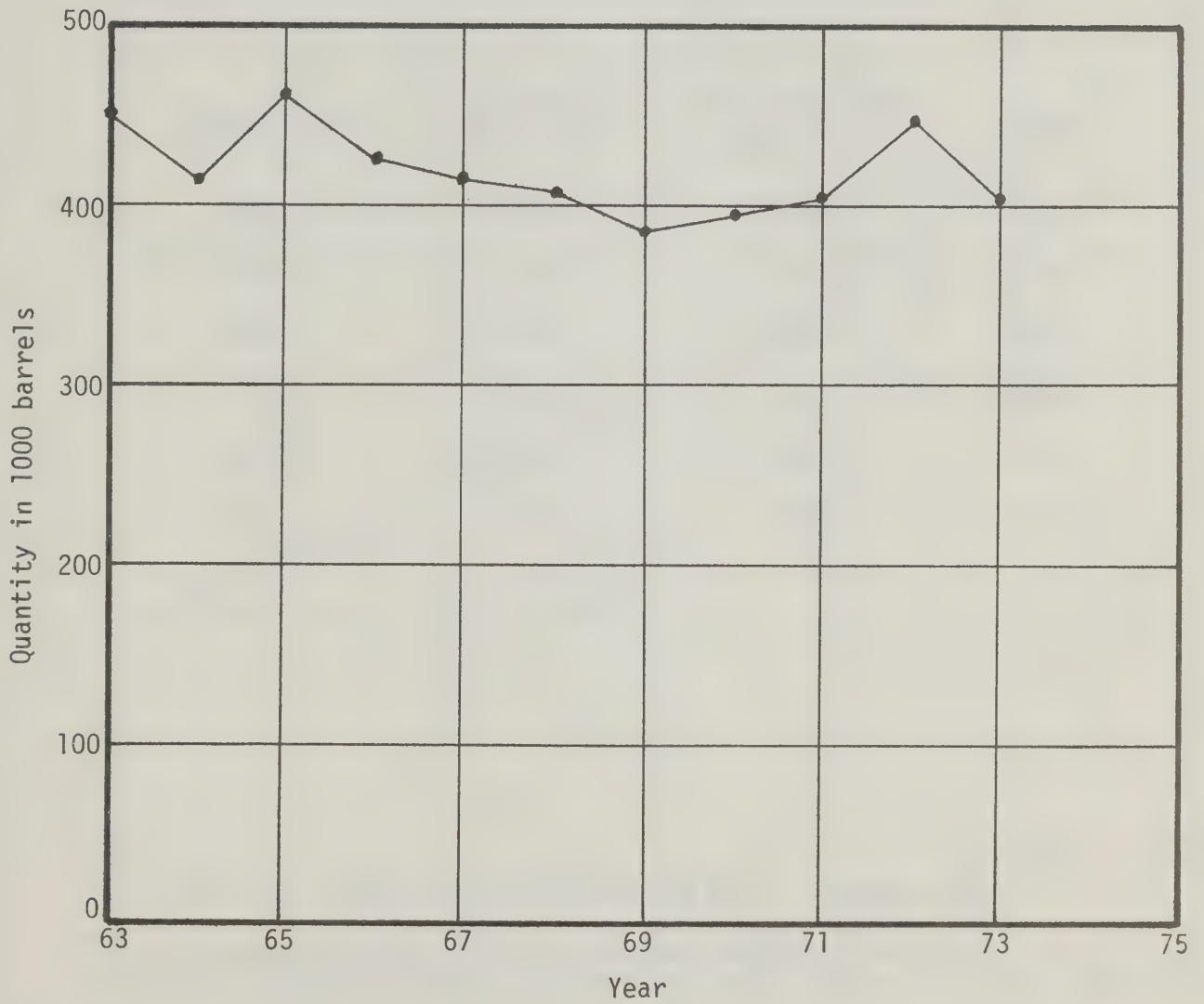


TABLE 5.5
PASSENGER AUTOMOBILE REGISTRATIONS
AND POPULATION FOR ONTARIO

<u>Year</u>	<u>Registrations (millions)</u>	<u>Population (millions)</u>	<u>Autos/Person</u>
1963	1.927	6.448	0.299
1965	2.140	6.731	0.318
1967	2.312	7.127	0.324
1969	2.502	7.385	0.338
1971	2.713	7.703	0.352
1973	3.002	7.939	0.378

Sources:

1. Registrations: "The Motor Vehicle, Part III," Publ. 53-219, Statistics Canada.
2. Population: Canada Year Book, 1974, Statistics Canada.



Figure 5.2

Actual and Projected Number of Passenger
Automobile Registrations in Ontario

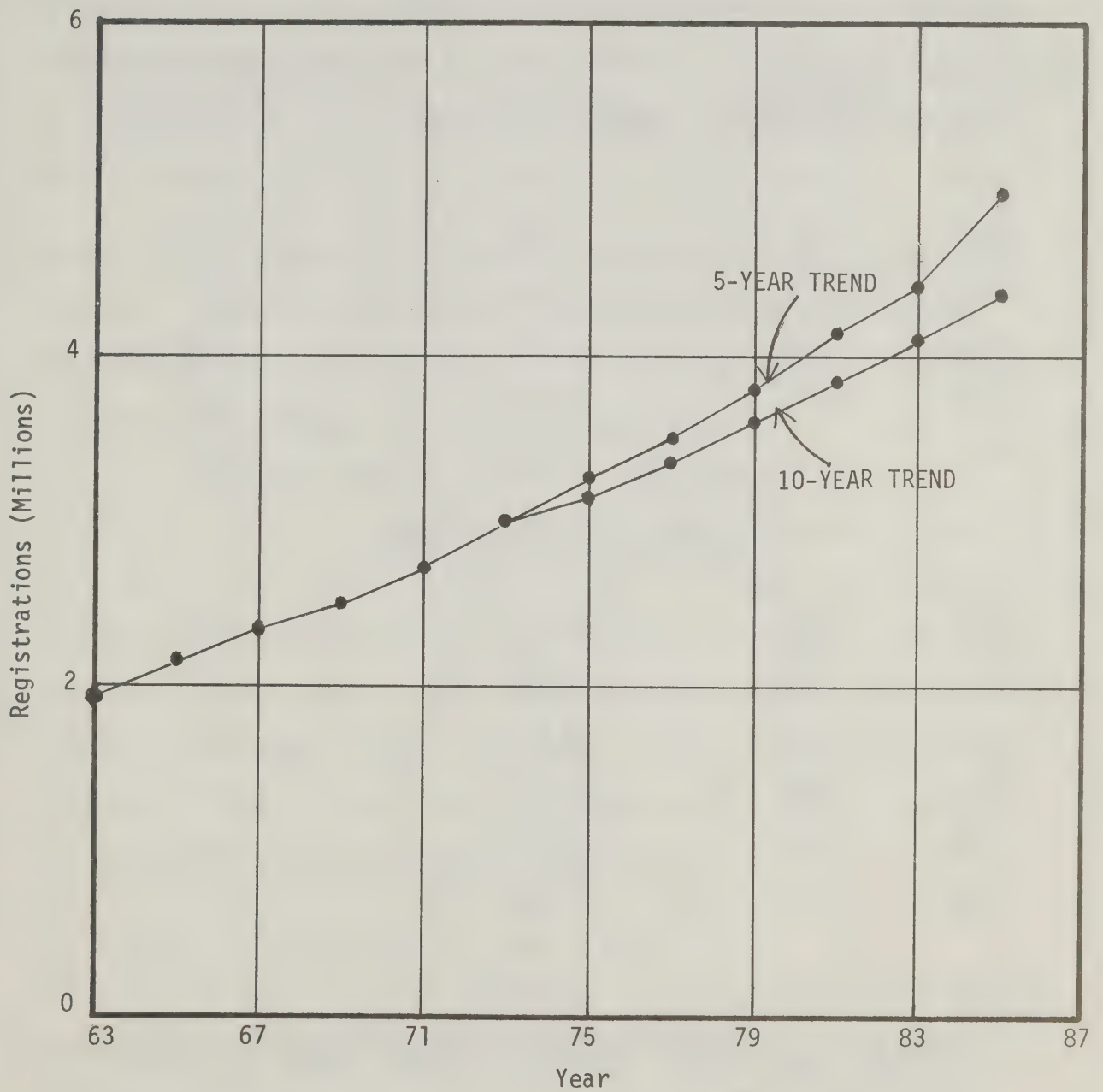


Table 5.6

PROJECTIONS OF PASSENGER AUTOMOBILE REGISTRATION

Based on Ten Year Trends

<u>Year</u>	<u>Projected Population (millions)</u>	<u>Projected Vehicles-Per-Person</u>	<u>Projected Number of Registrations (millions)</u>
1975	8.21	0.384	3.15
1977	8.48	0.398	3.38
1979	8.75	0.412	3.61
1981	9.03	0.426	3.85
1983	9.31	0.440	4.10
1985	9.60	0.454	4.36

Based on Five Year Trends

1975	8.21	0.395	3.24
1977	8.48	0.415	3.52
1979	8.75	0.435	3.81
1981	9.03	0.455	4.11
1983	9.31	0.475	4.42
1985	9.60	0.495	4.75

Sources:

1. Population: "Population Projections for Canada and the Provinces, 1972-2001." Publ. 91-514, Statistics Canada. Series C (low fertility) Projections.
2. Registrations: Obtained by multiplying projected population by extrapolated vehicles-to-persons ratios.



of 3.93 percent, while the ten year trend implies a growth rate of 3.27 percent.

The impact of increased gasoline prices and of government policy to discourage energy consumption and automobile use may make these trend projections optimistic, particularly for the period 1975-1980. For the United States, J.L. Helm* forecasts an annual growth rate in vehicle registrations of 2 percent from 1975 to 1980, and a slightly higher growth rate of 2.2 percent from 1980 to 1985.

Annual mileage figures for passenger automobiles were not available for Ontario. Estimates for the United States presented by the National Petroleum News are shown in Table 5.7 for selected years. A trend forecast from these figures, obtained from the regression

$$\log (\text{annual mileage}) = 9.122 + .0081 (\text{year})$$

is given in Table 5.7. Forecasts of United States automobile mileage, by J. L. Helm, show a drop in mileage per year continuing from the present until the late 1970's; after 1980 the annual increase in mileage is expected to reflect historical growth rates. These forecasts are given in Table 5.8. Combining the number of vehicle forecasts in Table 5.6 with the mileage forecasts in Table 5.7 and 5.8 yields forecasts of passenger automobile VMT for Ontario. These are given in Table 5.9.

5.2.2 Motor Oil Consumption Per Vehicle Mile

Motor oil consumption has two components: the gradual consumption of oil during normal operation and the replacement of dirty oil at periodic intervals.

* Helm, J. L., "The Outlook for Lubricants"; NPRA 73rd Annual Meeting; San Antonio, Texas; May, 1975.



TABLE 5.7
AVERAGE ANNUAL MILEAGE FOR
PASSENGER AUTOMOBILES IN THE U.S.

<u>Year</u>	<u>Annual Mileage</u>
1963	9378
1965	9387
1967	9531
1969	9786
1971	10121
1973	9992
1975	10263*
1977	10431*
1980	10689*
1985	11133*

*geometric trend projection

Source: National Petroleum News
Factbook, 1975.



TABLE 5.8
PROJECTED AVERAGE ANNUAL MILEAGE

<u>Year</u>	<u>Annual Mileage</u>
1975	10000
1977	9400
1980	10000
1985	10500

Source: J.L. Helm, "The Outlook
for Lubricants"; NPRA 73rd
Annual Meeting; San Antonio,
Texas; May, 1975.



TABLE 5.9
PASSENGER AUTOMOBILE VEHICLE MILES TRAVELED (VMT)
IN ONTARIO (BILLIONS)

<u>Year</u>	<u>10 Yr. Registration Trend</u>		<u>5 Yr. Registration Trend</u>		<u>Consensus*</u>
	<u>NPN</u>	<u>HELM</u>	<u>NPN</u>	<u>HELM</u>	
1973	30.0	-	30.0	-	30.0**
1975	32.3	31.5	33.3	32.4	31.9
1977	35.3	30.8	36.7	33.1	33.1
1980	39.9	37.3	42.3	39.6	38.6
1985	48.1	45.8	52.9	49.9	46.9

*In view of increased vehicle operating costs and reduced economic growth in the 1974-76 period, we take the average of the 10 year trend forecasts as a consensus forecast, noting that these figures may still be somewhat optimistic.

**Actual registrations times NPN average annual mileage estimate.



Data on oil usage were not available directly for Ontario. Thus, making the assumption that the vintage and size composition of the Ontario automobile stock is the same as that of the United States, we can use data available for America. Our first estimates of oil usage are drawn from a survey of service stations by the National Petroleum News (NPN). Total oil usage per mile can be obtained by dividing NPN figures for total oil usage per vehicle by average annual mileage. Furthermore, in the accounting relation

$$\text{Total oil usage per mile} = \left[\text{Oil consumption per mile} + \frac{\text{Crankcase capacity}}{\text{Miles between changes}} \right],$$

the oil consumption per mile figure can be determined from total oil usage per mile and NPN survey figures for crankcase capacity and miles between changes. These data are given in Table 5.10. A trend on oil consumption yields

$$\log \left[\frac{\text{consumption}}{\text{per 1000 mi}} \right] = -1.74 - .106 (\text{year}).$$

Use of this trend implies that oil consumption (expressed in Imperial quarts per 1000 miles) will drop to .0325 in 1977, .0237 in 1980, and .0139 in 1985. These figures imply oil consumption at the rate of one Imperial quart for every 4630 miles in 1973, dropping to one Imperial quart for every 18,000 miles in 1985. However, there is reason to believe that the trend above confounds the technological decrease in oil consumption with the gradual decline for the United States in service station sales as a proportion of total motor oil sales. The rate of technological improvement in oil consumption can be expected to be moderate. J. L. Helm forecasts a rate of oil consumption for United States automobiles of 0.10 Imperial gallons per 1000 miles through 1985. We believe this figure is more realistic, and adopt it



TABLE 5.10

OIL USAGE BY PASSENGER AUTOMOBILES IN THE U.S.

<u>Year</u>	<u>Oil Sold (Imp. Gals./ 1000 mi.)</u>	<u>Average Miles Between Oil Changes</u>	<u>Average Oil Capacity (Imp. Gals.)</u>	<u>Estimated Consumption (Imp. Gals./ 1000 mi.)</u>
1963	0.435	3458	1.04	0.134
1965	0.373	4179	1.06	0.119
1967	0.321	4984	1.08	0.104
1969	0.257	5876	N/A	0.077*
1971	0.220	6290	N/A	0.051*
1973	0.198	7380	N/A	0.054*

*Assuming oil capacity of 1.06 Imp. gals.

Source: National Petroleum News Factbook. Quantities converted to Canadian gallons from U.S. quarts.



for our forecasts. Note that this rate is higher than the NPN figure because it includes non-service station sales.

Utilizing the Helm estimates of miles between oil changes, oil capacity, and oil consumption given in Table 5.11, we obtain the forecasts of oil usage per vehicle mile given in Table 5.12.

It is possible to combine the VMT and oil usage forecasts to obtain a direct technological estimate of oil demand; these estimates are given in Table 5.13. The annual rates of change reflect Helm's forecast of a decline in miles driven per automobile in the mid-1970's, followed by a rapid recovery. Note that these technological estimates do not match with the observed retail sales in Ontario. This suggests that the technological conditions in Ontario may be different than in the U.S., or more importantly that Ontario retail sales contain substantial non-passenger and off-road components, i.e., sales of oils other than motor oils. In order to utilize the technological forecasts, we assume that these factors move in proportion to the technological usage variable, with the factor of proportionality determined by the overlapping year, which was 1973. Table 5.14 gives estimates of retail sales based on the technological sales figures, adjusted to 1973 observed retail sales. For comparison, a trend in retail sales from Table 5.4, using the trend formula

$$\log (\text{retail sales}) = 6.086 - .0079 (\text{year})$$

is also provided. We believe the adjusted technological forecasts to be the most plausible.

5.3 Non-Retail Sales

A large share of the lubricating oil consumed in Ontario is sold to



TABLE 5.11

PROJECTED OIL USAGE FOR U.S. PASSENGER CARS

(Quantities Converted to Canadian Gallons from U.S. Quarts)

<u>Year</u>	<u>Miles Between Oil Changes</u>	<u>Oil Capacity (Imp. Gals.)</u>	<u>Oil Consumption (Imp. Gals./ 1000 mi.)</u>
1973	5300	1.0	0.10
1975	5400	1.0	0.10
1980	6000	1.0	0.10
1985	7000	0.90	0.10

Source: J.L. Helm; "The Outlook for Lubricants"; NPRA 73rd Annual Meeting; San Antonio, Texas; May, 1975.



TABLE 5.12
FORECASTS OF OIL USE
PER 1000 VEHICLE MILES*

<u>Year</u>	<u>Use</u> <u>(Imperial Gal.)</u>
1973	.289
1975	.285
1980	.267
1985	.229

$$*(Use) = \frac{(Consumption)}{(Miles \text{ Between Changes})} + \frac{(Crankcase Capacity)}{(Miles \text{ Between Changes})}$$



TABLE 5.13
TECHNOLOGICAL PREDICTION
OF AUTOMOTIVE OIL DEMAND

<u>Year</u>	<u>Demand</u> <u>1000 Barrels</u>	<u>Annual Rate of Change</u> <u>Percent</u>
1973	247.7	----
1975	259.8	2.41
1977	262.0	0.42
1980	294.4	3.84
1985	306.9	0.90



TABLE 5.14
FORECASTS OF RETAIL SALES
(Units: 1000 Barrels)

<u>Year</u>	<u>Adjusted Technological Forecasts</u>	<u>Trend Forecasts</u>
1973	404	403
1975	424	397
1977	427	391
1980	479	382
1985	501	367



ultimate consumers through channels other than retail pump outlets. In 1973, such non-retail sales of lube oil amounted to 2.1 million barrels. Non-retail sales have increased rapidly, growing in the decade 1963-1973 at an annual trend of 7.3 percent. Sales figures are shown in Table 5.15. Table 5.16 gives a distribution of non-retail sales by end use, as reported by Statistics Canada for 1973, the last year available. Of the total, only 22 percent is allocated to specified end use categories; the remaining 78 percent is allocated to "other". These statistics reflect the failure of major refiners to accurately classify the sales by class of customer. The Ministry of Energy-Teknekron survey attempted to obtain a classification of "other," but, in most cases, the major suppliers did not provide consistent records of eventual end use. The companies appear to supply data for a few specific categories and to lump all remaining sales in the "other" category.

Given the presence of the large "other" category and the inconsistency of major firm reports, we have made no attempt to forecast end use demand components separately. The problems of variable definition appear to preclude this approach. We have instead made a forecast for total non-retail sales, and then apportioned these sales according to historical trends gathered from Statistics Canada publications and the Ministry of Energy-Teknekron questionnaires.

Several alternative formulations of a forecasting model for non-retail sales were tested; the most satisfactory in terms of base-line fit was

$$\log \left[\begin{array}{c} \text{non-retail} \\ \text{sales} \end{array} \right] = \begin{array}{cc} -.2478 & + \\ (.0552) & \end{array} 1.272 \log \text{RDP} \quad , \quad (1)$$

(.119)



TABLE 5.15
SALES OF LUBRICATING OILS
THROUGH CHANNELS OTHER THAN RETAIL PUMP OUTLETS
 (Units: 1000 Barrels)

<u>Year</u>	<u>Non-Retail Sales of Lube Oil</u>	<u>Year</u>	<u>Non-Retail Sales of Lube Oil</u>
1963	879	1969	1519
1964	938	1970	1471
1965	1045	1971	1562
1966	1385	1972	1653
1967	1319	1973	2078
1968	1368		

Source: "Refined Petroleum Products," Publication 45-208,
 Statistics Canada, Ottawa.



TABLE 5.16
SALES OF LUBRICATING OILS
BY SECTOR OF THE ECONOMY IN 1973
(Units: 1000 Barrels)

<u>Sector</u>	<u>Sales</u>	<u>Percentage</u>
Farms	80	3.8
Governments	45	2.2
Construction	88	4.2
Forest Products and Paper Industry	65	3.1
Mining and Related Industries	87	4.2
Railways	74	3.6
Marine	17	0.8
Other	<u>1622</u>	<u>78.1</u>
Total	2078	100.0

Source: "Refined Petroleum Products," Publication 45-208,
Statistics Canada.



where RDP is an index of Real Domestic Product for Ontario (1961 = 1.000), and non-retail sales are measured in millions of barrels. This regression had a $R^2 = .93$. The standard errors are presented in parentheses.

Figure 5.3 shows total non-retail sales and the fitted curve (using actual values for RDP).

Forecasts received from the Ministry of Transportation and Communications show projected annual growth rates in the RDP index for Ontario of 5.4 percent from 1970 to 1975, 5.2 percent from 1975 to 1980, and 4.7 percent from 1980 to 1985. Although these forecasts are not dated, they do not appear to take into account the 1974-75 recession. Hence, we have considered a variant of these forecasts in which the growth of RDP is one percent in 1974 and 0.0 percent in 1975, returning to the Ministry's growth rate projections after 1975. Table 5.17a gives RDP indices under these two alternative forecasts and the corresponding non-retail sales forecasts obtained from Equation (1).

An alternative approach to forecasting Ontario lube oil demand is to apply all-Canada forecasts on total lube and grease sales. These forecasts for rates of growth may be reasonably plausible for non-retail Ontario lube oil sales, since retail sales of lube oil and all grease sales are small fractions of the total. However, this requires that there be no systematic provincial differences in demand characteristics. Table 5.17b gives forecasts for non-retail sales in Ontario based on the assumption that these sales grow in a pattern paralleling the all-Canada total lube and grease sales forecasts until 1976, and thereafter grow at the rates given in the adjusted forecasts in Table 5.17a.



Figure 5.3

Non-Retail Sales of Lubricating Oils in Ontario

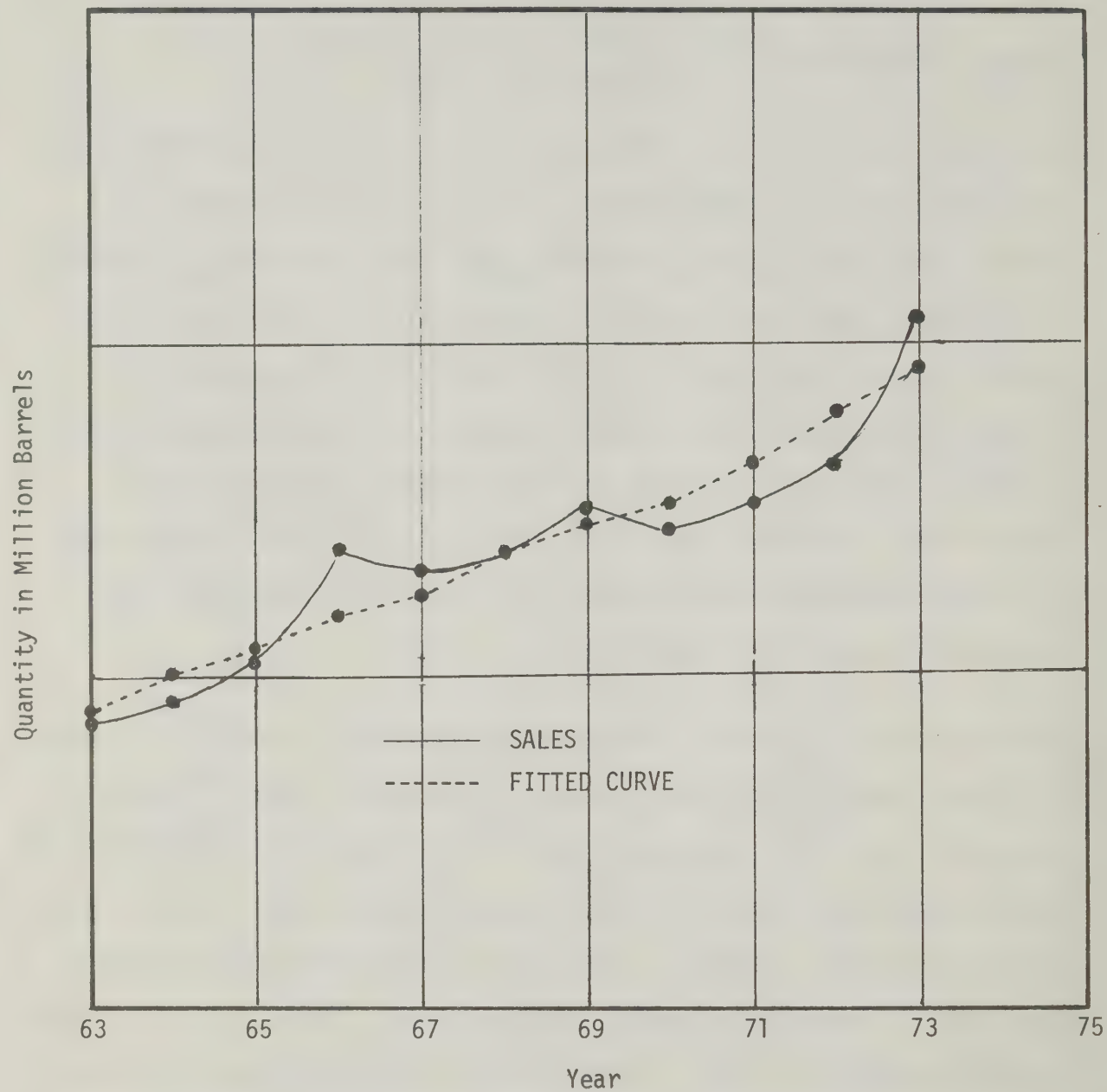


TABLE 5.17a
RDP AND NON-RETAIL SALES FORECASTS

$$\log \left[\frac{\text{non-retail}}{\text{sales}} \right] = -.2478 + 1.272 \log \text{RDP}$$

Equation (1) Unadjusted				Equation (1) Adjusted			
Year	RDP Index	% Change (a)	Predicted Sales (1000 bbl.)	% Change (a)	RDP Index	% Change (a)	Predicted Sales (1000 bbl.)
1973	2.039 (b)		2077 (b)		2.039 (b)		2077 (b)
1974	2.149	5.4	2210	6.4	2.149	5.4	2210
1975	2.265	5.4	2353	6.5	2.170	1.0	2236
1976	2.383	5.2	2501	6.3	2.170	0.0	2236
1977	2.507	5.2	2513	0.5	2.283	5.2	2375
1980	2.919	5.2	3194	8.3	2.658	5.2	2852
1985	3.672	4.7	4228	5.8	3.344	4.7	3770
Average							
74-85		5.0		6.1		4.1	
							5.0

(a) Annual rate
(b) Observed values. The predicted sales figures are computed by using the predicted rates of growth in Equation (1), starting from the observed 1973 sales.



TABLE 5.17b
NON-RETAIL SALES FOR ONTARIO PREDICTED
USING ALL-CANADA FORECASTS TO 1976

<u>Year</u>	<u>Predicted Sales^(c)</u>	<u>Index of Predicted Sales</u>	<u>% Change^(c)</u>
1973	2077 ^(a)	98.7	---
1974	2210	100.0	1.3
1975	2051	92.8 ^(b)	.94
1976	2144	97.0 ^(b)	.45
1977	2287	103.5 ^(b)	6.7
1980	2778	125.7	5.0
1985	3719	168.3	6.0
<u>Average</u>			
74-85			4.8

(a) actual

(b) "Present and Projected Lubricant Situation in Canada 1975-1985"; Department of Industry, Trade, and Commerce; Ottawa; December, 1975.

(c) Annual rate



Among the forecasts given in Tables 5.17a and 5.17b, we believe that the one made in Table 5.17a using Equation (1) and adjusted RDP values is the most plausible. Hence, we utilize this in our remaining forecasts.

5.4 Total Sales of Lubricating Oil

The retail sales forecast from Table 5.13 and the non-retail sales forecast from Table 5.17a can be combined to yield a composite forecast for total lube oil sales in Ontario from 1975 to 1985. These results are given in column 4 of Table 5.18.

From Table 5.3, the reported total lube oil sales by major producers in 1974 was 3.0 percent higher than 1973, in contrast to the predicted growth rate of 5.8 percent obtained from Equation (1). The reported figures may suggest an upward bias in forecast total sales because of an overestimate of 1974 growth in RDP. If in fact growth in demand from 1973 to 1974 were at the 3.0 percent rate, then total demand would be 2555 thousand barrels in 1974, 2591 in 1976, 2728 in 1977, 3243 in 1980, and 4159 in 1985.

5.5 Sales by Type of Oil

Table 5.3 provides a breakdown by type of oil of total sales by major suppliers in Ontario. Table 5.19 expresses this distribution in percentage terms. The distribution shows very little variation over time. For the purpose of forecasting, we have computed an average distribution by taking the average of the distributions for the years 1970-74. This average distribution is given in Table 5.20. The distribution in Table 5.20 compared with the all-Canada distribution of production suggests that either a) major oil companies (BP, Gulf, Imperial, Petrofina Canada, Shell, Sun, and Texaco) are overrepresented in the industrial oil market and underrepresented in



TABLE 5.18
TOTAL SALES OF LUBRICATING OIL
(1000 bbl.)

<u>Year</u>	<u>Retail</u> ^(c)	<u>Non-Retail</u> ^(b)	<u>Total</u>	<u>% Change</u>
1973	404*	2077	2481 ^(a)	---
1974	414	2210	2624	5.8
1975	424	2236	2660	1.4
1976	425	2236	2661	0.0
1977	427	2375	2802	5.3
1980	479	2852	3331	5.9
1985	501	3770	4271	5.1

(a) Observed total, from Table 5.1.

(b) From Table 5.17a--Equation (1) Adjusted.

(c) From Table 5.14



TABLE 5.19

PERCENTAGE DISTRIBUTION OF SALES OF LUBRICATING OILS & GREASES BY YEAR,
FOR THE PROVINCE OF ONTARIO

(Units: Percents)

<u>Oils</u>	<u>1969*</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>
Automotive						
Crankcase Oils	36.44	38.98	39.10	37.41	38.49	37.11
Hydraulic Oils	6.90	5.91	6.69	5.97	5.58	6.32
Gear Oils	2.07	2.03	2.02	1.99	2.16	2.05
Miscellaneous	N/A	.03	.04	.05	.06	.06
	45.41	46.95	47.85	45.42	49.29	45.54
Industrial						
Engine Oils	3.20	3.51	4.15	4.14	3.73	3.73
Hydraulic Oils	15.88	15.88	16.23	19.55	16.35	17.10
Gear Oils	2.37	2.32	2.34	2.08	2.00	2.11
Metalworking Oils	3.58	5.06	3.37	3.55	3.79	3.30
Process Oils	21.08	18.65	17.90	17.17	18.65	19.47
Miscellaneous	8.40	7.60	8.07	8.06	9.18	8.71
	54.51	53.02	52.11	54.55	53.70	54.42
<u>Greases</u>						
Automotive	35.65	35.10	40.14	44.69	46.10	42.12
Industrial	64.34	64.89	59.85	55.30	53.91	57.87

*One respondent out of seven did not submit a report for 1969.

Source: Survey of Major Marketers By Ministry of Energy.



TABLE 5.20

AVERAGE PERCENTAGE DISTRIBUTION OF SALES
OF LUBRICATING OILS AND GREASES IN ONTARIO AND CANADA

	<u>Ontario</u> ^(a)	<u>Canada</u> ^(b)
Automotive		
Crankcase Oils	38.1	52
Hydraulic Oils	6.2	3
Gear Oils	2.1	2
Miscellaneous	<u>0.1</u>	<u>-</u>
	46.5	57
Industrial		
Engine Oils	3.7	7
Hydraulic Circulatory and Turbine Oils	16.9	13
Gear Oils	2.2	2
Metalworking Oils	3.5*	1
Process Oils	18.9	17
Miscellaneous	<u>8.3</u>	<u>3</u>
	53.5	43

*The entry in Table 5.20 for metalworking oils for 1970 was omitted from the averaging, because it appeared to be unreliable. Averages were scaled slightly in order to obtain a sum of 100.00%

(a) Survey of Major Marketers

(b) "Present and Projected Lubricant Situation in Canada 1975-1985"; Department of Industry, Trade, and Commerce; Ottawa; December, 1975



the automotive oil markets, or b) in comparison to Canada as a whole, Ontario is a heavy consumer of industrial oil relative to automotive oils. We believe the latter to be the case, and thus maintain the assumption that Table 5.20 is an accurate forecast of total as well as major product distribution in Ontario.

Utilizing the total sales forecasts in Table 5.18 and the percentage distribution in Table 5.20, we obtain the forecasts of demand by type of oil shown in Table 5.21.

5.6 Sales by Type of Trade

Table 5.1 displays sales of lube oils by type of trade in Ontario which are available from Statistics Canada for the years 1963-1973. These data contain a very large "other" category representing sales of unknown destination.

The survey of major lube oil suppliers requested a detailed breakdown by end use in order to clarify the distribution of sales of oils and greases by type of trade. The objective was to reduce the "other" classification and to provide data for sales in the categories "commercial road transport," "steel and metallurgical plants," "utilities", and "other manufacturing". The response was mixed, with one firm supplying no information and the others submitting reports with varying degrees of detail. Table 5.22 gives reported non-retail sales from the survey as a percentage of Ontario non-retail sales reported by Statistics Canada. Table 5.23 gives the survey response. However, there is some evidence that sales for resale outside Ontario are included in the reported totals; please refer to Table 5.2 in this regard.



TABLE 5.21

FORECAST OF LUBRICATING OIL SALES IN ONTARIOBY TYPE OF OIL

(Units: 1000 barrels)

	<u>1975</u>	<u>1980</u>	<u>1985</u>
<u>Automotive oils</u>			
Crankcase	1013	1269	1627
Hydraulic	165	207	265
Gear	56	70	90
Other	3	3	4
<u>Industrial Oils</u>			
Engine	98	123	158
Hydraulic	450	563	722
Gear	59	73	94
Metalworking	96	117	149
Process*	503	630	807
Other	221	276	354

*May contain base stocks sold to blenders.



TABLE 5.22

MINISTRY OF ENERGY--TEKNEKRON SURVEY RESPONSE
AS A PERCENTAGE OF ONTARIO NON-RETAIL SALES
OF LUBE OILS AND GREASES

<u>Year</u>	<u>Percentage</u>
1969	82
1970	89
1971	85
1972	85
1973	71



TABLE 5.23

SALES OF LUBE OILS & GREASES TO ULTIMATE CONSUMERS, ONTARIO, 1969-1974

(Units: 1000 Barrels)

	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>
Retail Pump Outlets	248.42	291.14	308.74	306.40	301.83	342.08
Construction	66.28	65.91	68.51	68.35	75.03	81.65
Farms	52.16	48.91	51.00	51.25	63.09	64.77
Forest Products & Paper Industry	71.39	71.17	72.49	77.39	79.37	81.60
Mining, Smelting, Quarrying, & Petroleum Exploration	82.42	82.08	87.86	77.34	92.80	95.54
Railways	46.61	56.47	69.73	73.62	67.43	70.62
Marine	4.19	5.82	5.36	6.26	7.71	6.97
Commercial Road Transport	154.06	153.47	146.68	140.41	164.69	163.37
Steel & Metallurgical Plants	196.46	256.11	252.48	292.52	257.04	253.51
Other Manufacturing	386.59	393.52	384.21	442.66	427.91	435.24
Governments	24.48	24.50	26.03	25.69	26.71	26.81
Utilities	99.33	90.24	87.90	81.74	112.74	131.23
Others	<u>105.36</u>	<u>106.20</u>	<u>119.92</u>	<u>125.06</u>	<u>141.85</u>	<u>131.80</u>
Total	1537.81	1645.54	1681.17	1768.63	1818.43	1884.31

Source: Survey of Major Oil Companies by the Ministry of Energy.



Table 5.24 compares the survey responses with Statistics Canada figures for Ontario (from Table 5.1). We note that the distributions implied by these sources are at considerable variance and shift from year to year. Factors contributing to this variability are the large undistributed "other" category in the Statistics Canada figures and the variation in reports by the surveyed firms.

Table 5.25 shows a composite breakdown of non-retail sales. This distribution was obtained by combining Statistics Canada data for 1970-73 with the data for additional categories in the survey. All quantities are expressed as percentages of non-retail lube oil and grease sales. Table 5.26 also gives an average distribution of sales by type of trade, computed by averaging the four columns in Table 5.25. Combining Tables 5.18 and 5.25, we obtain forecasts of non-retail sales by type of trade, as shown in Table 5.27.

5.7 Supply and Disposition of Lube Oils and Greases

The overall flow of lube oils and greases in and out of Ontario is described in Table 5.28. Sources of supply include production, inventory changes, net deliveries from major marketers and distributors, and foreign imports. The "production" figure is a composite of refinery output (of both base stocks and finished oils), oil additives and other materials and of inter-product transfers. These inter-product transfers consist mainly of reclassifications of partially finished base stocks previously classified as products other than lube oils and greases. Imports include only receipts from foreign countries into Ontario. Data on lube oil supply are displayed graphically in Figure 5.4.



TABLE 5.24

COMPARISON OF QUESTIONNAIRE RESPONSES WITH STATISTICS
CANADA FIGURES. SHOWN ARE PERCENT RATIOS OF
QUESTIONNAIRE ENTRIES TO STATISTICS
CANADA FIGURES.

<u>Sector</u>	<u>Year</u>		
	<u>1969</u>	<u>1971</u>	<u>1973</u>
Retail	62	76	74
Construction	N/A	115	80
Farms	74	71	75
Forest Products and Paper	N/A	164	119
Mining, etc.	N/A	67	96
Railways	92	80	88
Marine	27	45	47
Governments	39	47	60
Total	78	83	71



TABLE 5.25
SALES OF LUBE OILS AND GREASES AS PERCENTAGE OF
TOTAL NON-RETAIL SALES

	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>
Construction	5.22	3.66	4.00	4.38
Farms	5.92	4.41	4.38	3.94
Forest Products and Paper	3.29	2.71	2.74	3.11
Mining, etc.	5.77	8.15	7.96	4.48
Railways	4.15	5.36	5.14	3.55
Marine	0.93	0.71	0.82	0.81
Governments	3.24	3.38	3.60	2.11
Road Transport	10.07	9.04	8.15	7.71
Steel and Metallurgical Plants	16.80	15.52	17.06	12.01
Utilities	5.91	5.42	4.78	5.28
Others	38.70	41.64	41.37	52.62

Note: All quantities shown are percentage ratios to Statistics Canada totals for non-retail sales of lube oils and greases. Sales figures for categories "construction" through "governments" are taken from "Refined Petroleum Products." Sales figures for "road transport," "steel and metallurgical plants" and "utilities" are taken from the Ministry of Energy survey. Percentages for "other" sales are obtained simply by subtracting the sum of all other percentages from 100.0.



TABLE 5.26
SALES OF LUBE OILS AND GREASES AS PERCENTAGE OF
TOTAL NON-RETAIL SALES
(Average Values for 1970-1973)

<u>Sector</u>	<u>Average</u>
Construction	4.3
Farms	4.7
Forest Products and Paper	3.0
Mining, etc.	6.6
Railways	4.6
Marine	0.8
Governments	3.1
Road Transport	8.7
Steel and Metallurgical Plants	15.3
Utilities	5.3
Other	43.6



TABLE 5.27

ESTIMATED SALES OF LUBRICATING OIL BY TYPE OF TRADE(Units: 1000 Barrels)

<u>Sector</u>	<u>1975</u>	<u>1980</u>	<u>1985</u>
Construction	96	123	162
Farms	105	134	177
Forest Products and Paper	67	86	113
Mining, etc.	148	188	249
Railways	103	131	173
Marine	18	23	30
Governments	69	88	117
Road Transport	195	248	328
Steel and Metallurgical Plants	342	436	577
Utilities	119	151	200
Others	975	1243	1644



TABLE 5.28

SUPPLY AND DISPOSITION OF LUBE OILS AND GREASES IN ONTARIO

(Units: 1000 Barrels)

Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
<u>Supply</u>												
Production	1711	1644	1689	1648	1749	1789	1774	1853	1826	1885	2066	2199
Net change in inventories	19	4	-37	-123	2	-49	54	7	108	-39	99	-248
Net receipts from other companies in Canada	50	83	109	74	91	118	105	91	142	180	345	377
Foreign Imports	555	738	1023	1214	1029	1021	1169	775	818	1089	1145	1274
Total Supplied	2335	2469	2783	2813	2871	2880	3102	2726	2893	3115	3655	3602
<u>Disposition</u>												
Net inter-provincial transfers	860	948	1123	1075	1112	1026	1044	783	796	915	1149	967*
Foreign Exports	1	2	2	2	3	3	2	1	8	1	0	0
Sales of lube oils	1332	1354	1505	1810	1739	1776	1904	1869	1968	2101	2481	2649*
Sales of greases	64	71	71	73	64	61	68	65	65	71	68	
Adjustments	77	94	83	-147	-46	13	84	9	56	27	-44	-14*
Total Disposed	2335	2469	2783	2813	2871	2880	3102	2726	2893	3115	3655	3602

*Estimates--not comparable to previous years.

Note: Figures may not total exactly because of rounding.

Source: Statistics Canada publications #45-204 and #45-208.

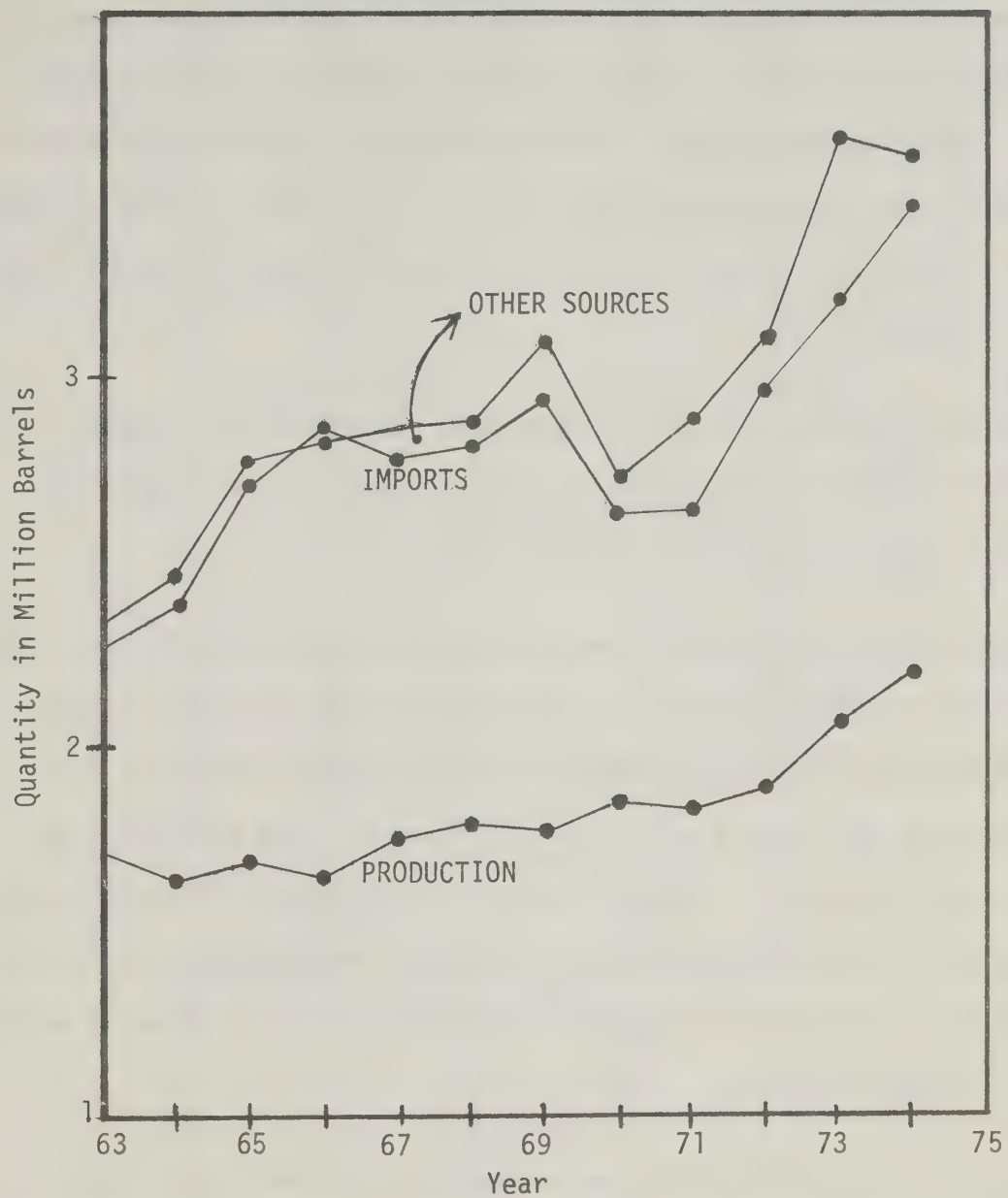


Figure 5.4

Sources of Supply of Lubricating Oils and Greases



The total supply is apportioned among several channels of disposition. A large portion of the lubes flows out of Ontario to other provinces as "net inter-provincial transfers". Foreign exports are generally very small. The entry "adjustments" includes losses, oil for own consumption by producers and census adjustments. Finally, net sales of lube oils and greases in Ontario are shown separately. These data are displayed graphically in Figure 5.5.

In Table 5.29, average daily production (365 days/year) is compared with daily finished lube refining capacity in Ontario. Finished lube capacity for all of Canada is also included.

From 1963 to 1970, the ratio of production to capacity exceeds 100 percent. This apparent contradiction arises from deficiencies in both the production and capacity figures. As mentioned above, the "production" figure is an estimate derived from a combination of straight lube production and inter-product transfers. On the other hand, the capacity figures include only the main large refining plants in Canada. Nevertheless, the figures indicate that in recent years production has been running somewhat below full capacity in Ontario.

Inventories and receipts from other companies have generally played a small role in the supply picture. Imports, on the other hand, accounted for 35% of total supply in 1974. Imports increased rapidly from 1963 to 1965 in response to rising demand from both inside and outside Ontario. They remained fairly constant from 1965 to 1969, except for temporary peaks in 1965 and 1969 - a response to peaks in lube oil demand in those years. The sharp drop in imports in 1970 coincides with the opening of a



Figure 5.5

Disposition of Lubricating Oils and Greases
(not including adjustments)

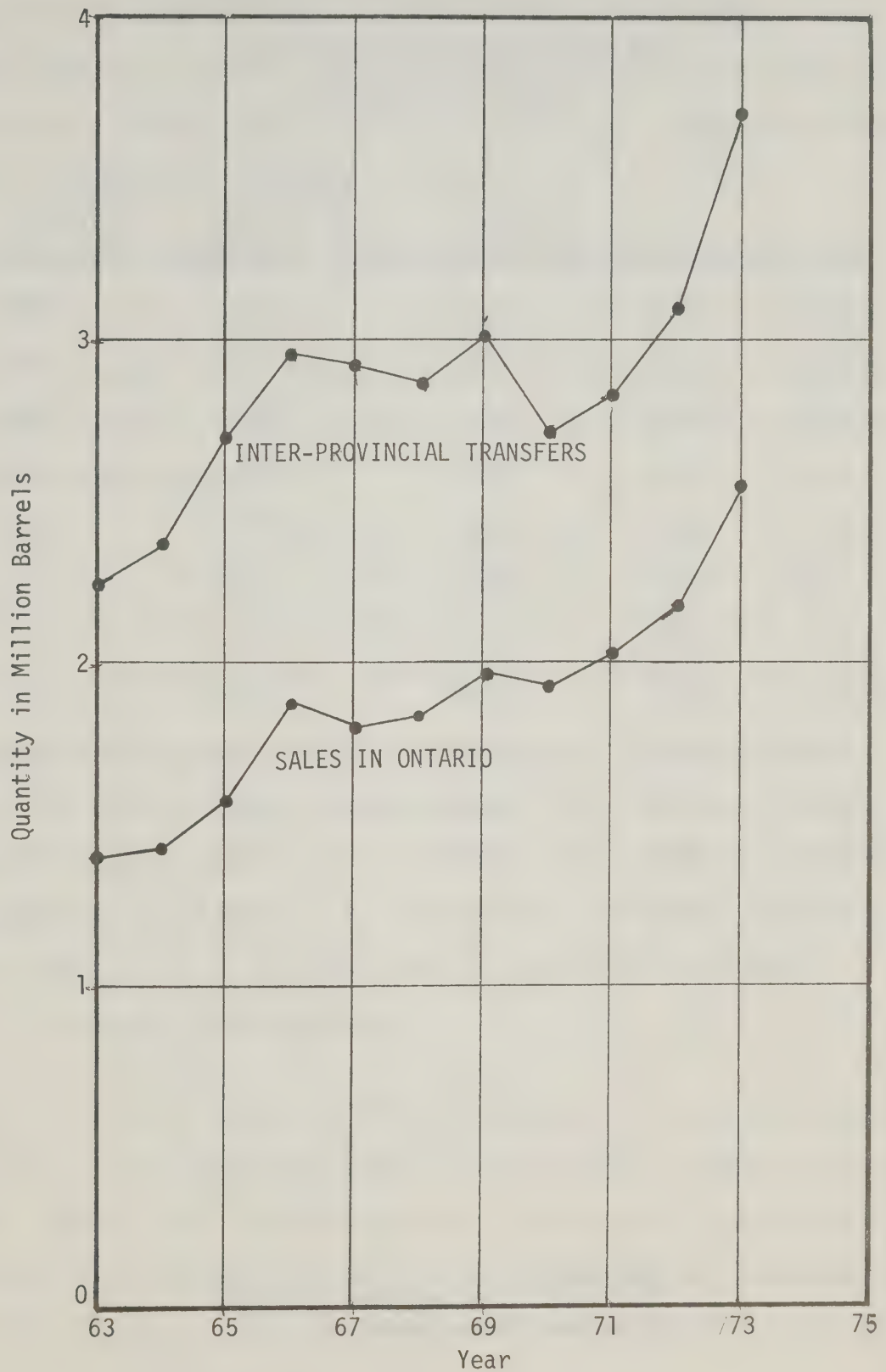


TABLE 5.29

FINISHED LUBE REFINING CAPACITY COMPARED WITH
REFINERY PRODUCTION IN ONTARIO
 (Units: Barrels/day)

<u>Year</u>	<u>Production(1)</u>	<u>Ontario Finished Lube Capacity(2)</u>	<u>Production As Percent Of Capacity(3)</u>	<u>Canada Finished Lube Capacity(2)</u>
1963	4688	4420	106	6750
1964	4504	4420	102	7020
1965	4627	4420	105	7020
1966	4515	4350	104	6910
1967	4792	4650	103	7210
1968	4901	4650	105	7010
1969	4860	4650	105	9370
1970	5077	4650	109	9570
1971	5003	5850	86	11470
1972	5164	5850	88	11710
1973	5660	7150	79	13210
1974	6025	7050	85	13110

Sources: 1. Table 5.28
 2. National Petroleum News Factbook
 3. Based on 365 day/year.



major refining facility (Shell) in Montreal; a similar sharp drop is also seen in inter-provincial transfers. Since 1970, imports have once again climbed steadily at a linear trend with slope 140,000 bbl/year since 1971. This trend will probably continue until the addition of major new refining facilities by Gulf (see Section 5.8 below).

Inter-provincial transfers out of Ontario have followed essentially the same trends as imports. In fact, in most years, imports and transfers are fairly close in magnitude. Thus, Ontario serves in effect as a way-station for a large portion of foreign imports consumed in other provinces. Foreign exports have been negligible.

Sales of greases constituted only two percent of the total supply and three percent of lube oil and grease sales in 1973. Grease sales have fluctuated considerably but have exhibited little tendency to grow steadily.

5.8 Impact of New Refinery Capacity on the Lube Oil Supply in Ontario

In late 1975, Gulf Oil Canada announced plans to construct a new lube oil refinery at Clarkson, Ontario. The purpose of this section is to evaluate the impact of this new facility on lube oil supply in Ontario and to discuss the implications of this new source of supply for investment in facilities for waste oil re-refining.

The plant is slated to open in 1979 with a reported lube producing capacity of 5900 bbl/day. This amount represents a large fraction of existing Canadian capacity: 44% of total Canadian capacity (13,410 bbl/day in 1975) and 84% of Ontario's capacity (7050 bbl/day in 1975). (See Table 5.30.) If operated at 90% of capacity, the new refinery will produce 1.94 million barrels



TABLE 5.30
FINISHED LUBE CAPACITY, BY PLANT
IN CANADA, 1963 - 1975

<u>Year</u>	<u>Gulf Clarkson Ontario Plant</u>	<u>Gulf Montreal Quebec Plant</u>	<u>Imperial Oil Ltd. Edmonton Alta. Plant</u>	<u>Sarnio Ont. Plant</u>	<u>Shell Montreal</u>	<u>TOTAL</u>
1963	1,220	330	2,000	3,200		6,750
1964	1,220	600	2,000	3,200		7,020
1965	1,220	600	2,000	3,200		7,020
1966	1,150	560	2,000	3,200		6,910
1967	1,150	560	2,000	3,500		7,210
1968	1,150	560	1,800	3,500		7,010
1969	1,150	560	1,800	3,500	2,360	9,370
1970	1,150	560	2,000	3,500	2,360	9,570
1971	1,150	560	2,700	4,700	2,360	11,470
1972	1,150	560	2,700	4,700	2,600	11,710
1973	1,150	560	2,900	6,000	2,600	13,210
1974	1,150	560	2,900	5,900	2,600	13,110
1975	1,150	560	2,900	5,900	2,900	13,410

Source: National Petroleum News Factbook, McGraw-Hill, 1963.
Units: Barrels/Day



of lubes per year, an amount comparable to Canada's total imports in 1974 (1.78 million barrels). The opening of such a large refinery is bound to have repercussions well beyond the borders of Ontario. Therefore, it will be necessary to look at the entire Canadian supply picture.

Fortunately, there is a precedent to Gulf's proposed venture. In 1969, Shell opened a new refinery in Montreal. Its lube capacity, 2360 bbl/day, added 34% to Canadian capacity existing in 1968 and 421% to the capacity existing in Quebec. The opening of the plant radically altered the flow of lubes in Canada. The transformation is described in Table 5.31. In 1968, Quebec produced only 18% of the lubes it consumed. Of the remainder, 37% came directly from foreign sources and 46% from other provinces, principally Ontario. In 1970, production reached 90% of consumption, foreign imports dropped to 12%, and the province became a net exporter of oil to other provinces. The near self-sufficiency of Quebec led to large reductions in foreign imports in other provinces as well. (Note that the figures shown in Table 5.31 are net flows and do not describe actual inflows and outflows of lube products.)

The principal changes in net lube flows are depicted in Figure 5.6. From 1968 to 1970, consumption increased only modestly while production outside of Quebec rose only by a small amount. The primary impact of the 748,000 bbl increase in Quebec's production (87% of the Shell plant capacity) was a reduction of 635,000 bbl in foreign imports. This reduction was distributed throughout Canada in three ways:

1. A reduction of 245,000 bbl in direct imports into Quebec.
2. A reduction of 246,000 bbl in direct imports into Ontario, with



TABLE 5.31

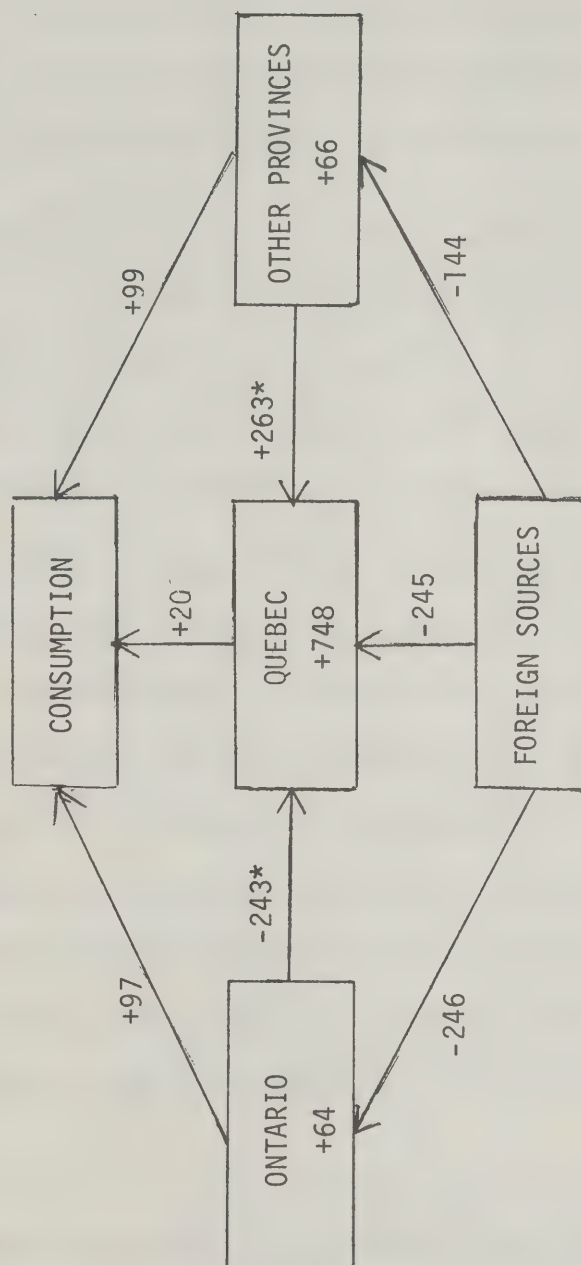
IMPACT OF SHELL REFINING FACILITY IN QUEBEC

	<u>Ontario</u>		<u>Quebec</u>		<u>Other Canada</u>	
	<u>1968</u>	<u>1970</u>	<u>1968</u>	<u>1970</u>	<u>1968</u>	<u>1970</u>
<u>Supply</u>						
Production	1789	1853	179	927	775	841
Inventories	-49	7	-48	14	48	-23
Net receipts from other cos.	118	91	70	36	53	12
Imports	<u>1021</u>	<u>775</u>	<u>372</u>	<u>127</u>	<u>429</u>	<u>285</u>
Total	2880	2726	573	1104	1303	1115
<u>Disposition</u>						
Interprovincial transfers	1026	783	-462	44	-564	-827
Exports	3	2	2	1	0	0
Sales of Oils and Greases	1837	1934	1004	1024	1867	1966
Adjustments	<u>13</u>	<u>9</u>	<u>29*</u>	<u>35*</u>	<u>2</u>	<u>-24</u>
Total	2880	2726	573	1104	1303	1115

*Changed to make totals agree; original figures do not add up correctly

Figure 5.6

Changes in Major Lube Flows From 1968 to 1970
In Response to Opening of New Refinery



* See Note 3.

Notes:

1. All quantities in 1000 barrels.
2. Numbers inside boxes represent changes in production.
3. Changes in interprovincial transfers are net changes and do not represent actual volumes of trade.
4. Exports, net receipts from other companies, changes in inventories, and adjustments not shown. Hence, flows do not cancel completely.



a concomitant reduction of 243,000 bbl in Ontario's exports to other provinces.

3. A reduction of 144,000 bbl in imports to provinces other than Quebec and Ontario. Inter-provincial transfers to these other provinces increased by 263,000 bbl.

In addition to these, small changes occurred in minor sources of supply, such as inventories and receipts from other companies in Canada.

The current supply situation in Ontario differs substantially from that of Quebec in 1968. Although Ontario showed foreign imports of 1,145,000 bbl in 1973, the province exported an almost identical amount, 1,149,000 bbl, to other provinces in Canada. Thus, Ontario seems to act as a "port of entry" for a large portion of Canadian lube imports. In fact, in 1974, imports into Ontario accounted for 72% of Canadian imports, while consumption in Ontario was only 43% of the total. On the other hand, production in Ontario has not risen as fast as consumption in recent years. In 1970, lube sales exceeded lube production by 81,000 bbl (4% of sales), but by 1973 the gap had widened to 483,000 bbl (19% of sales). If sales increase by 663,000 bbl from 1973 to 1979 (assuming constant grease sales) as indicated by our forecast, the gap could widen to at most 1,150,000 bbl well below the projected production of Gulf's plant. About 790,000 bbl would be left over for export to other parts of Canada, or perhaps even to foreign countries.

These calculations clearly show that the opening of the new refinery will have strong repercussions within Ontario and beyond the borders of Ontario. A full assessment of the plant's impact would require a comprehensive analysis and forecast of the entire Canadian lube oil supply-demand situation.



Such a broad study is beyond the scope of this report; nevertheless, a simple analysis of the Canadian lube oil situation can provide a perspective for assessing the impact of the Gulf refinery.

The supply and disposition of lube oils and greases for all of Canada is described in Table 5.32. Since 1970, sales of lubes have risen at an average annual rate of 6.0 percent, while production has climbed at 5.9 percent. The gap between sales and production has widened slowly from about 1.30 million bbl to 1.37 million bbl. Imports have risen at a faster rate, from 1.19 to 1.78 million bbl, although one should note that in 1974, 440,000 bbl were absorbed by inventories, somewhat distorting the supply picture.

According to the forecast by the Department of Industry, Trade and Commerce,* Canadian sales of lube oils and greases will grow from 6.16 million bbl in 1973 to 6.89 million bbl in 1979, an increase of 730,000 bbl.

On the other hand, our forecast for Ontario alone indicates an increase of 660,000 bbl by 1979, which, if extended proportionately to all Canada in the same ratio as 1973, suggests an increase of about 1.6 million bbl by 1979. Since we have not studied in any detail the future demand for lube oil outside of Ontario, we will accept the Department's forecast in the following analysis.

Next to demand, the second element to be considered is refining capacity. Although no entirely new refineries have been built in Canada since the

* "Present and Projected Lubricant Situation in Canada, 1975-1985."



TABLE 5.32

SUPPLY AND DISPOSITION OF LUBE OILS AND

GREASES FOR ALL OF CANADA

(Units: 1000 Barrels)

	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>
<u>Supply</u>							
Production	2743	2937	3621	3624	3964	4110	4558
Inventories	-49	74	-2	271	-71	112	-440
Other Cos.	241	226	139	205	191	277	325
Imports	<u>1822</u>	<u>1852</u>	<u>1187</u>	<u>1276</u>	<u>1556</u>	<u>1647</u>	<u>1780</u>
Total	4756	5088	4945	5375	5639	6147	6223
<u>Disposition</u>							
Lube Oils & Grease Sales	4708	4885	4924	5268	5518	6162	6222*
Exports	4	4	2	8	1	2	1
Adjustments	<u>44</u>	<u>199</u>	<u>20</u>	<u>99</u>	<u>120</u>	<u>-17</u>	<u>0*</u>
Total	4756	5088	4945	5375	5639	6147	6223

*Not exactly comparable to previous years

Source: Statistics Canada, Publication 45-004



Shell plant, refining capacity at existing plants has increased by 37% from 1970 to 1974. As mentioned above, the increases in production on the whole kept pace with the increases in sales from 1970 to 1974. If this trend continues we can expect imports to increase slowly from their 1974 level of 1.8 million barrels. The fact that demand is expected to grow at rates lower than those in the past suggests also that gradual increases in capacity at existing plants may be sufficient to meet most increases in sales. Indeed, the Department's forecast calls for almost no change in Canadian imports over the next decade.

These considerations, together with the preceeding analysis of the opening of the Shell plant, lead to the conclusion that the primary impact of the new Gulf refinery will be a drastic reduction in Canadian imports of lubes. The expected production from the plant coincides with the expected level of imports, so that for a short period, at least, Canada may come close to self-sufficiency in the production of lubes. Since 72% of Canadian imports enter through Ontario, the location of the plant in that province will make the process of replacing imports with domestic production even easier. As with the Shell refinery, massive shifts in the pattern of flow of lubes can be expected within a brief period after the opening of the plant. The frictions encountered in such shifts are likely to lead to oversupply of particular products and particular regions, with lower oil prices as a result.

The period immediately preceeding and following the opening of such a relatively large plant is likely to be full of uncertainty for both producers and consumers of lubes. The sudden dislocation of established



patterns of supply may pose additional difficulties for any new re-refineries to be built in the last half of the present decade. This is especially true for a re-refinery attempting to compete for sales of base stocks in the wholesale (blender) market. Production from the Gulf refinery will initially exceed that company's requirements for sales to ultimate consumers. While Gulf attempts to expand their final user market, they will be forced to sell excess lube production to firms who now depend on other Canadian refiners and imports for base stock supply. As Gulf's sales to ultimate consumers rise, the fraction of production from the new facility which is made available to blenders will, of course, fall. During this period total Canadian lube oil demand will also increase, thereby, reducing the pressure on wholesale prices.

A re-refinery serving the industrial market, such as the closed-cycle facility described in Chapter 2, would be less vulnerable to competition from other marketers following the opening of the Gulf refinery. This is because the closed-cycle re-refiner is providing a service rather than a product to his industrial clients. If the re-refiner was able to compete successfully in the final user market in order to establish his industrial business, the existence of increased price competition brought on by a temporary supply surplus would not change the advantage a user gains by dealing with a firm which can both supply quality oil and eliminate the problem of waste oil disposal. Conversely, in the wholesale market, a re-refiner can compete only on the basis of price. Should a re-refiner be unable to meet the price offered by other suppliers, a blender has little reason to do business with him.



There exists one additional possibility: a large portion of the new production could be diverted to other countries, especially the United States. This occurrence would represent a departure from the historical trend of almost zero exports of lubes. J. L. Helm* has predicted that lube supply in the U.S. will keep well ahead of demand over the next 10 years. These two factors, combined with the hindrance of tariff barriers, seem to rule out the possibility of large exports to the U.S.

* Helm, J. L.; "The Outlook for Lubricants."



6. SURVEY OF ATTITUDES TOWARD RE-REFINED PRODUCTS AND ASSESSMENT OF MARKET POTENTIAL

6.1 Indroduction

The purpose of this chapter is to report the results of a study of the practices and attitudes of commercial and industrial consumers as they related to the indroduction and utilization of re-refined lubricating oil products. In this study "commercial" means commercial transportation, and "industrial" refers to firms that utilize lubricating oils in their production processes, thus excluding those in which lubricating oils become part of the product.

There is also a third market, which consists of lube oil blenders. This third market exists because base lubricating oil requires different chemical additives for various end-uses. Blenders include the major oil companies who refine base lubricating oil and independent blenders. There are a number of independent blenders within Ontario who currently purchase base lubricating oil stocks from major oil refiners and blend in specific additives to meet the requirements of specialized markets. These blenders compete with the major oil companies that refine crude oil and perform their own blending. A blender is able to compete successfully with the majors because:

1. He has earned a reputation for producing a high quality product or specific type of product, or
2. His marketing activities focus on specialized end uses, especially in the industrial section.

Since commercial and industrial firms and blenders represent potential markets for an oil re-refiner, in-depth interviews



were conducted with a selected group of these companies in Ontario. The goal of the interviews was to determine the attitudes of these firms towards the use of re-refined oil products.

Section 6.2 is a summary of the interviews with commercial and industrial firms. Section 6.3 is a summary of responses of representatives of industrial and commercial firms to a number of the key questions asked during the interviews.

Section 6.4 presents the results of the interviews with blending firms. Section 6.5 is a summary of the survey of attitudes and an evaluation of the potential future demand for re-refined oils. Section 6.6 is a summary of the marketing channels for lubricating oil in Ontario.

An assessment of the attitudes of retail consumers toward the use of re-refined crankcase oil in private cars has not been included in this study. Assessments of this market are available elsewhere.¹

The intention of this chapter is to focus on the commercial and industrial sectors in which relatively few buyers purchase large quantities of lubricants. Thus, a re-refiner might concentrate his initial efforts on this sector with a limited marketing budget.

The purpose of the study was to explore the attitudes and practices of firms regarding lube oil purchase, use, and disposal. Accordingly, a detailed questionnaire was developed to guide in-depth personal

¹Teknekron, Inc., "A Technical and Economic Study of Waste Oil Recovery - Part II: An Investigation of Dispersed Sources of Used Crankcase Oils," EPA Contract 68-01-1806, June 1974.



interviews in a systematic manner. (This questionnaire is found in Appendix 2 of Volume 2 of this report.)

Preliminary consultation of census publications suggested that the time and available funds would be best spent on studying large users of lube oils in a few key industries, e.g. steel, fleet trucking, industrial tools and parts, etc. Interviews were held with 31 individuals representing 22 firms. In several instances, it was possible to interview both purchasing managers and "users" of lube oils. The time required for the interviews ranged from an hour and 15 minutes to two and one-half hours, with the mode requiring 1 hour and 45 minutes.

The interviews took place in Toronto, Burlington, Hamilton, and St. Catherine's during a total of two work weeks; a portion occurring in December, 1975 and a portion in late January, 1976.

Following the interviews, detailed notes were prepared of the various responses that resulted from the questions contained in the questionnaire.

The response of persons interviewed ranged from extreme openness to various degrees of caution. Specifically, in the latter case, answers to questions regarding prices, quantities and specifics of waste oil handling were avoided.

At the beginning of each interview, the respondent(s) was told that the purpose of the study was to understand industry-wide practices and attitudes regarding lubricating oils. It was explained that



references to individual firms would not appear in the report nor would there be a transfer of data, in any form, referencing the name of the firm.

6.2 Summary of Interviews with Commercial and Industrial Firms

On the basis of our experience with the study of buying decisions by industrial organizations, and given the specific purpose of the study, we decided that the best allocation of the interview time would be to the following areas:

- Characteristics of interviewee(s) and firm
- Types and volumes of lubricating oils purchased
- Lubricating oil prices
- Purchasing process
- Security of supply
- Potential substitution
- Use of Re-refined Oil
- Use of synthetic oil
- Disposal of waste oil
- Government regulations

The questionnaire was designed to provide a logical flow of probing questions. A number of questions served as cross-checks for answers to previous questions. Great care was taken not to mention the word "re-refined oils" during the early parts of the interview. Introduction of the subject of re-refined oils did not actually occur until the 27th question.



6.2.1 Characteristics of the Interviewee and Firm

Information regarding these characteristics is given by answers to questions 1, 6a, 6b, and 6c (see also questions 2, 3a, 3b, 4, 5, and 6d in the questionnaire). Section 6.3 contains the tabulation of answers to these questions.

All the respondents had the responsibility for purchasing lubricating oils. Technical support was sometimes required during the interview from engineers and research and development personnel. Some of the respondents were not only responsible for purchasing the lubricating oils but were also responsible for their use.

The number of years that the interviewee had been purchasing or utilizing lubricating oils covered a wide range; the least amount of experience was 2 years, the most was 27 years. Over 60 percent of those interviewed had in excess of 10 years of experience. The (arithmetic) average was 11.8 years.

A major portion of the firms interviewed were either subsidiaries or divisions of major organizations, with over half of these ownerships being outside of Canada. All the remaining firms had ownership within Canada or within Ontario.

Eleven manufacturing companies were interviewed. Of these firms, two produce tools and parts for the automotive industry, three manufacture steel and steel products, one manufactures rubber goods, and five manufacture a diversity of products. Four transportation firms, including one railroad and three trucking companies, were



interviewed. Two of the trucking firms are closely held and managed organizations; the third is a decentralized organization with individual driver ownership of the tractors and some trailers. There was also an interview with a city government.

The total number of employees represented by the firms interviewed was in excess of 80,000; the highest number of employees in a single firm was about 35,000, the lowest was 350. The arithmetic average number of employees was over 5,000, and the mode was slightly greater than 1,200 employees.

6.2.2 Lubricating Oils Purchased (Types and Volumes)

Questions 7, 8, 9, and 10 focused on the types and volume of lube oils purchased during the year preceeding the interview. The total amount of lubricating oil purchased by the firms interviewed in Ontario was in excess of 2.5 million gallons annually. The largest purchase was 1,770,000 gallons per year; the smallest was 3,000 gallons per year. The arithmetic average was approximately 180,000 each year, with the mode at approximately 60,000 gallons per year.

The 1975 forecast for industrial lubricated oil sales presented in Table 5.21 indicate the following market segmentation:

	<u>Million Imperial Gallons</u>	<u>Percentage</u>
Hydraulic Oil	15.750	31.5
Metalworking Oil	3.36	6.7
Gear Oil	2.065	4.1
Engine Oil	3.430	6.9
Process Oil	17.605	35.3
Other	7.735	15.5
	<u>49.945</u>	<u>100.0</u>



The 2.5 million gallons accounted for in the interviews represent about 5% of the forecasted sales of industrial oils in Ontario for 1975.

Types of lubricating oils purchased by the firms interviewed are listed below in order of decreasing annual consumption.

- Hydraulic oils (rust and oxidation and anti-wear)
- Metal working oils (cutting oils)
- Process oils
- Gear oils
- Other

This ranking is consistent with historical and projected volumes consumed by all industrial firms in Ontario.

While the ranking by categories coincided with the forecast in Chapter 5, the percentages did not closely relate. The interviews indicated that more than 20 percent of the oils were used for metal-working processes, as compared to the 6.7 percent projected for 1975 sales. In a similar manner, process oils accounted for about 20 percent of the oil volume as compared to 35.3 percent projected for 1975 sales in Ontario.

There are several hundred oil classifications based on usage and additives; not all oils can be readily assigned to the categories used in the interviews nor in the questionnaires sent to the major oil suppliers (refer to Chapter 5). Therefore it is doubtful that the coincidental similarity in the ranking of oil volumes indicates a representative interview population.



Within the commercial transport industry, our interviews indicate that the potential use of re-refined oils might be precluded by the existence of engine warranty guarantees ranging up to the life of the engine. These warranties typically specify the type of oil required. Partially as a result of this situation, the major centrally managed trucking firms interviewed have contractual arrangements for lube oil supply with major oil companies.

The centrally managed trucking firms had made a corporate decision to rely on a single supplier for all oils purchased. One firm was even following a program of ownership of a single class of engine to eliminate the possibility of using the wrong oil in an engine. The target objective of this firm was to overhaul engines and change oil each 100,000 miles. The inadvertant use of the wrong oil had caused, in the past, more frequent overhauls at a cost of from \$2,500 to \$3,500 for each engine.

The one trucking firm, where individual drivers own the vehicles, did not have a central maintenance facility. Rather, the owner/driver was responsible for purchasing the type of oil required for his tractor.

The major portion of the firms that were interviewed had specifications for lubricating oils readily available. Typical specifications were governmental and major oil company specifications; other suppliers could use these to provide quotations for comparable oil classifications. Two of the firms interviewed had been dealing with



the same vendors for a number of years and received a specifically designed oil product; they were not aware of the specification. Such a situation would tend to block entry of an alternative supplier of lubricating oil products.

6.2.3 Lubricating Oil Prices

Questions 13, 17a and 17b focus on lubricating oil prices. A number of firms did not respond to these questions. For those firms that did, the total annual purchase was approximately \$6,000,000; the high was \$3.8 million and the low was \$4,500 each year. The arithmetic average was approximately \$500,000 a year; the mode was about \$160,000 a year.

There seems to be a tendency for the bulk of lubricating oil purchases in any given year to be from a single vendor, with other suppliers of general lubricating oils and specialty oils providing a much smaller portion. The bulk of the purchases were from the major oil companies. Only on two occasions were the majority of purchases made from a lubricating oil blender rather than a major oil company.

6.2.4 Purchasing Process

Questions 11, 14, 15, 16, 17, 18, 21, 22, 23 and 25 focus on the purchasing process for lubricating oil products in the respondent's firm. The purchasing department and the company's engineering or research and development departments have about equal influence in the selection of lubricating oils (see question 11). As a cross-check, a ranking of importance of different sources of influence was requested in question 16.



Responses to question 11 indicated that the company research and development engineers were the most important influence in product selection, and that the interviewee's office was the next important influence. Question 16 asked for a ranking by a first and second choice. Responses indicated that "my own office" dominated; the "company engineers" were consistently mentioned as the second most important influence. Probing during the interviews indicated that the typical practice in firms having an engineering staff was to have the engineer supply acceptable specifications. In some cases the engineer also supplied a list of acceptable suppliers. On several occasions the engineering personnel recommending specifications and suppliers were not located in Canada. In a few cases, the corporate officers provided the vendor selection. In these cases the same vendor had been supplying all the oil to the firm for a number of years.

With regard to the factors that lead to the selection of specific vendors, answers were relatively balanced between "prompt delivery" and the "vendor's technical services." "Prompt delivery" was the most important consideration for firms where critical production processes could be interrupted by the unexpected loss of lubricating oil in the machinery. "Technical assistance" from vendors was important, even in cases where a firm had its own specialized lubricating oil research and development capabilities.

Most of the prices established for the sale of lubricating oils came from "competitive bidding" or from "competitive bidding followed



by negotiation." In one case, at the direction of the company President, the individual "just paid the requested price" from a vendor he had been dealing with for 15 years.

One of the most interesting practices uncovered is the increasing association of the purchase of lubrication products with the purchase of other products, such as gasoline, diesel fuel, grease, raw materials, and other merchandise, from a single vendor (see questions 17 and 18). The existence of this association could make it difficult for new lube suppliers to gain entry. In fact, not one of the interviews revealed a situation where the major purchases of lubricating oils were from firms different from those supplying other products listed in the questionnaire.

None of the firms interviewed was able to report a predesignated plan of approach should there be a sudden shortage of oil. Each firm, however, felt that the recent price trends were in excess of real cost increases. Only two of the respondents had thought about the potential of re-refined oil as a substitute should the price for virgin lube oils be greatly increased.

Only one of the firms interviewed indicated knowledge of changes in materials, machinery or production processes that may affect future purchasing of lubricating oils. However, this firm, which anticipated a doubling of lubricating oil requirements, purchased only 3,000 gallons a year.



6.2.5 Security of Supply

Questions 12, 19a, 20a and 24 pertain to the security of lubricating oil supply.

Respondents indicated that maintaining an adequate inventory of lubricating oils ranged from "somewhat important" to "not very important." Those firms that thought it was important to maintain an adequate inventory were making such comments in relationship to specific types of oils used in process equipment where uninterrupted service is essential to the firms' production.

All interviews indicated that historically there had been no difficulty in obtaining the desired quantities of oil. Similarly, the interviews indicated that no firm had experienced difficulty in obtaining the proper quality of lubricating oil. Only a few interviewees indicated that within the next five years they expected a significant change in either the quantity or quality requirements for any of the lube oils now used.

6.2.6 Potential Substitution

Question 26a focused on the concept of potential substitutions. Up to this point, no mention had been made of either re-refined or synthetic lubricating oils.



With the exception of four firms, neither types of oils were mentioned during the interview by the respondent. Two of these firms were "recycling" from 100,000 to 200,000 gallons of oil annually using equipment owned by the company. The other two firms were planning to install their own equipment in order to recycle from 300,000 to 500,000 gallons yearly. Recycling means a cleaning process involving only filters and centrifuges rather than the type of re-refining processes described in Chapter 1.

6.2.7 Use of Re-refined Oil

Questions 27 through 40, with the exception of 30 and 35, focus on various aspects of the use of re-refined oil.

Four of the firms interviewed were using or had used re-refined oils. This represents about 25 percent of the firms interviewed. This unexpectedly high percentage was probably due both to the selection of those firms expected to use large quantities of oil and to the fact that 8 of the firms were located in Hamilton where a re-refiner had formerly been operating. Of the four firms which had used re-refined oil, three had been using it in 1975.

The organization that had ceased using re-refined oil was a city government. The city had been purchasing oil from a re-refiner because of the requirement that the vendor be selected on the basis of competitive bidding. However, in the most recent competitive selection for lube oil supplies the re-refiner had been underbid by a major oil company by a few percent.



One of the three firms currently using re-refined oil is a major railroad. The railroad purchased about 3 million gallons of virgin oil and about 700,000 gallons of re-refined oil in 1975. An automobile parts manufacturer had been using re-refined hydraulic oil, but did not reveal the quantity purchased. The remaining firm using re-refined products was a steel company. The steel company purchased about 300,000 gallons of hydraulic and 200,000 gallons of gear oils annually. However, the records were not totally applicable for the year 1975 because the re-refiner had gone out of business in that year.

When asked if they expected to pay a different price for re-refined oils than virgin oils, most respondents demurred. The typical response was that they had not given the idea any thought. Those respondents who indicated that they would expect a price differential gave rather specific answers as to what the price differential should be. Typical answers were "10% less," or "10 cents a gallon less," with one individual saying that the price differential must be extremely large for him to consider the use of re-refined oils. Two of the firms that would not expect a price differential normally evaluate the quality of oils purchased through a series of laboratory tests.

There did not seem to be any consensus as to whether "re-refined oils would compete strongly with virgin oils now being used."



However, respondents believed that re-refined oil would compete should there be either rapid price increases for or restrictions in the supply of virgin lube oils.

Most respondents felt that blends of re-refined and virgin lube oils would not make re-refined oils more acceptable. In contrast, most respondents indicated that the use of re-refined oil would be more acceptable if major oil companies were to produce and/or distribute re-refined oils. The rationale for this answer was that major oil companies have extensive marketing and technical services staffs needed to promote these re-refined products, and that the major oil companies would be expected to produce a product of acceptable quality.

6.2.8 Use of Synthetic Oil

Questions 41 through 49 focused on synthetic lube oils. However, of the firms interviewed, none had actually used synthetic oils. Two steel companies believed that a specific fire-resistant oil used in steel making, commonly known as "synthetic oil," is a synthetic oil. However, this product is, in fact, a petroleum based lubricant.

In summary, none of these firms had actually used a synthetic lubricating oil and only two of the firms interviewed had even considered the potential. One of those firms was a trucking company that was considering the use of synthetic crankcase oils. The other firm



had heard of synthetic oils, but after a quick review found them to be too expensive and relatively unproven.

6.2.9 Waste Oil Disposal

Questions 50a, 51a, 51b, 52a, 52b, 53a, 54, 56 and 58 focus on waste oil disposal.

Most of the firms interviewed did not use their waste oils internally, although three firms used their waste oil as fuel. Two of these firms were steel companies where large amounts of oil that had been contaminated with animal and/or vegetable fats were burned. The compounding of mineral oil with vegetable and/or animal fats is typical in the preparation of "roll oils" used in the steel production process. All three firms using the burning disposal method mixed waste lubricating oils with fuel oil prior to burning.

Companies that did not use their waste oil internally had it removed by oil collection firms. In most cases waste oil removal was free.

The highest price paid to a collection firm was 10 cents a gallon; the lowest price paid was 3 cents a gallon. In one instance, a firm was paid to have the waste oil hauled away. The payment was a flat fee of \$500 annually. However, the interviewee had no records of the quantities of oil removed.

Only one firm had a contract for waste oil removal. In 5 cases a single company collected all the respondent's waste oil. In 9 cases more than one collector was involved.



Only two of the firms interviewed separated their waste oil by class of service.

For the seven firms that maintained records, the total quantity of waste oil collected was in excess of 100,000 gallons annually. The range was from 48,000 gallons to 2,000 gallons per year. The arithmetic average was 16,000 gallons a year. Data on the quantity of waste oil collected annually appeared to be extremely poor.

6.2.10 Government Regulations

The closing question was "Are your options for waste oil disposal now limited by government regulation?" All of the respondents indicated there was no real limitation. Although several firms indicated that they were aware that the disposal methods used by the collection firms may be regulated, no one mentioned the specific disposal practice used by the collection firm.

6.3 Summary of Numerical Analysis Pertaining to Commercial and Industrial Interviews

Summaries of responses to specific questions asked during the interviews with commercial and industrial firms are provided below. Only those quantifiable questions have been summarized. A complete listing of all questions used during the interview may be found in Appendix 2 of Volume 2 of this study.

The numbers listed before the questions below are the same as those used in the questionnaire.



SUMMARY OF QUANTIFIABLE RESPONSES TO QUESTIONS USED IN THE ATTITUDE INTERVIEWING PROCESS

A. Some people in your office are "Purchasing" or "Using but not purchasing".

12 questionnaires dealt with purchaser of lube oils.

4 questionnaires dealt with users of lube oils.

B. About how long have you been doing your present kind of work?
(Years, Months)

11.8 is the arithmetic average number of years of experience of the interviewee.

Most years of experience is 27 years.

Least years of experience is 2 years.

6a. Are you classified as a subsidiary, division, independent or something else?

6 are subsidiaries

4 are divisions

3 are independent

3 are something else

6b. What is your main line of business services or products?

11 are manufacturers, as follows:

2 produce tools and engines related to the automotive industry

1 produces rubber products

5 produce diversified products

3 are basic steel producers

4 are freight transporters

1 is a city government

∴ How many plant workers are employed here? (Number of workers)

Total employees: 84,710

Average number of employees: 5,294

Highest number of employees: 35,000

Lowest number of employees: 350

9. Approximately how many gallons of lube oil have you bought in the last year?

Total amount purchased: 2,537,499 gallons

Average amount purchased: 181,250 "

Highest amount purchased: 1,770,000 "

Lowest amount purchased 3,000 "

2 did not respond

11. Now, would you please look at the list below. In your experience, which one of these is the most important influence in the selection of lubricating oils?

5 believed their R & D engineers were determinative

3 believed their own office (Purchasing) was determinative

2 believed the original equipment manufacturer was determinative

1 believed their own company's foreman was determinative

1 believed their purchasing department was determinative

4 did not respond

12. How important is it for your company to maintain an adequate inventory of lubricating oil on hand? Would you say very important, somewhat important, or not very important?

6 thought it was very important

6 thought it was somewhat important

4 thought it was not very important

13. The total purchases of lube oils vary a great deal from industry to industry and from firm to firm. In the past year, what was the total dollar purchase for all lube oils?

Total dollar purchases: \$5,978,871

Average dollar purchases: \$ 543,534

Highest dollar purchases: \$3,800,000

Lowest dollar purchases: \$ 4,500

5 did not respond

14. There are several factors that lead to the selection of vendors, and their relative importance may vary with each type of oil. Could you tell me which of these factors is most important in the selection of a vendor?
 MOST IMPORTANT: 5 chose prompt delivery

6 chose vendor's technical services

2 chose vendor's maintaining a sufficient inventory

1 said it was selected by "corporate headquarters"

1 said the distribution of business by oil suppliers to interviewee was most important

1 did not respond

SECOND MOST IMPORTANT: 6 chose prompt delivery

6 chose vendor's technical services

1 chose vendor's inventory

1 chose vendor's R & D commitment

2 did not respond

15. How is the price established for lube oils? By competitive bid, negotiation, a combination of those two or some other way?

12 chose competitive bid

7 chose competitive bid followed by negotiation

3 chose negotiation

1 said that he "just pays requested price"

16. In your experience, which of the following people listed below is the most important in the selection of a vendor for your lube oils?

MOST IMPORTANT: 9 chose their own office (Purchasing)

4 chose their company's engineers

2 said higher corporate officers imposed the selection

1 chose financial department

SECOND MOST IMPORTANT: 6 chose their own office (Purchasing)

3 chose their company's engineers

2 chose their company's foreman

2 chose their company's truck drivers

1 chose their company's plant manager

2 did not respond

17 & 18. Correlation of vendors of lubricating oils to vendors of other products.

correlation of 5 vendors was revealed 5 times

correlation of 4 vendors was revealed 2 times

correlation of 3 vendors was revealed 3 times

correlation of 1 vendor was revealed 4 times

19a. During the past year have you experienced difficulty in getting the quantity of some lube oils you needed?

All who responded said they had NO difficulty.

20. Have you had difficulty getting the proper quality of lube oil you needed at any time during the past year?

14 had no difficulty

1 had had difficulty and changed suppliers

1 did not respond

21. Do you expect substantial changes in your quantity and quality needs for any of the lube oils you currently buy?

Change in the next year or so:

2 expected a change

14 did not expect a change

Change in the next 5 years or so:

5 expected a change

10 did not expect a change

1 did not respond

26a. Has anyone in your company given some thought about possible substitutes for each of the oils you are currently buying?

4 had considered it

10 had not considered it

2 did not respond

27a. Have you ever used re-refined lube oils in your operation?

12 had not used

4 had used



- 28a. Has this use of re-refined oil generally been under experimental conditions or is it in regular use?
 4 used it regularly
 0 used it experimentally
 12 did not respond or said such question was not applicable
- 28b. *IF THE USE OF RE-REFINED OIL IS EXPERIMENTAL: Is this in the laboratory or on the actual production floor?*
 2 said they used it in both situations
 14 did not respond or said it was not applicable
- 31a. Are you still experimenting with the use of re-refined lube oils or have you put them into general use or have you decided against further experimenting or use?
 3 had put it in general use
 1 is no longer using
 12 did not respond or said the question was not applicable
33. Do you believe that re-refined oils will compete strongly with virgin lube oils now being used?
 5 believed they would compete
 3 believed they would not compete
 8 did not respond
34. Would you expect to pay a different price for lubricating oils made from re-refined stock rather than from the original refined stock?
 3 would not expect a price differential
 4 would expect a price differential
 9 did not respond
36. What amount or percentage would you expect to see as to the differential for a quart, gallon, etc.
 2 thought 10% less
 1 thought 10¢/gallon less
 1 thought much less
 12 did not respond
38. The future (increase in) use of re-refined lube oils by your company may depend on a number of factors. Which of the factors would be the most important in making a decision about using re-refined lube oils?
 MOST IMPORTANT: 4 chose lack of availability of virgin oil
 3 chose price advantages
 2 chose taxation advantage
 1 chose company machinery
 1 chose engineer's change of view
 1 chose information about vendors
 4 did not respond
 SECOND MOST IMPORTANT: 4 chose lack of availability of virgin oils
 3 chose information about vendors
 1 chose engineer's change of view
 8 did not respond
39. Do you think a blend of re-refined and virgin lube oils might make re-refined oils more acceptable and thereby increase usage?
 4 thought it would be more acceptable
 11 thought it would not be more acceptable
 1 did not respond
40. If re-refined oils were produced and distributed by major refiners, do you think they would be more acceptable to companies who might be able to make use of re-refined oils?
 11 thought they would be more acceptable
 4 thought they would not be more acceptable
 1 did not respond
- 41a. Have you ever used synthetic lube oils in your operation?
 12 had not use
 3 had used*
 1 did not respond

*Further checking indicated confusion as to the meaning of synthetic oil, and in reality no firm interviewed had used synthetic oil.

- 50a. What method(s) do you use for disposing of your waste oil? Do you use it internally, or do you do something else with it?
- 5 used it internally
 - 11 did not use it internally
 - 1 did not respond
- 51a. Do you pay the company which disposes of your waste lube oil to pick it up and take it away?
- 5 exchanged value in some way
 - 3 did not pay
 - 8 did not respond
- 51b. How much do they charge you per gallon?
- 5 responded with a money figure
 - Average of these 5 is 6.5 cents/gallon
 - Highest is 10 cents/gallon
 - Lowest is 3 cents/gallon
 - 3 said there was no money exchanged
 - 8 did not respond
- 52a. Does the company that does the disposal pay you for the waste oils?
- 1 said they were paid
 - 15 did not respond
- 52b. How much do they pay you per gallon?
- 1 cited a single fee of \$500/year
 - 15 did not respond
- 53a. Are there contractual arrangements for waste oil removal?
- 8 said there was no contract
 - 1 said there was a contract
 - 7 did not respond
54. Is your waste lube oil picked up by more than one company?
- In 9 cases it was picked up by more than one company
 - In 5 cases only one company picked it up
 - 2 did not respond
56. Are the oils segregated by class?
- 11 firms do not segregate waste oil
 - 2 firms do segregate waste oil
 - 3 did not respond
58. What is your yearly quantity of waste lubricating oil disposed?
- 7 had a total annual quantity of 113,430 gallons/annum
 - Average of these is 16,204 gallons/annum
 - High quantity is 48,000 gallons/annum
 - Low quantity is 2,000 gallons/annum
 - 9 did not respond



6.4 Summary of Interviews with Lubricating Oil Blenders

6.4.1 Introduction

The lubricating oil "blending" industry is a potential market for re-refined oils. Therefore, interviews to assess attitudes and practices in the blending industry were conducted in January 1976.

This subsection consists of the following parts:

- Definition of an Independent Blending Company
- Market Served by the Blender
- Blenders in Ontario
- Market Segmentation in Ontario
- Volumes of Base Lubricating Oils Required
- Prices Paid for Base Lubricating Oils
- Base Lubricating Oil Specifications
- Attitudes Toward and Knowledge of Re-refining and Recycling

6.4.2 Definition of an Independent Blending Company

For the purpose of this study and in order to establish a specific market segmentation, an "independent blending company" is defined as a firm that produces finished lubricating oils by blending base oils obtained from a refiner or re-refiner with chemical additives. The blending company is further defined as not being one of the major oil companies.

6.4.3 Market Served by the Blender

Blenders compete in the marketplace with major refiners (and with other blenders) on the basis of: (a) a reputation for producing



a high quality product or specific type of product, and (b) marketing activities that focus on a specific market segment. Although they compete with the major oil companies, blenders in Ontario purchase almost all of their base lubricating oil from the majors.

6.4.4 Blenders in Ontario

There are about seven major blenders located in Ontario whose individual annual sales volume exceeds one million Imperial gallons of product. The largest of the seven in 1975 sold slightly more than seven million gallons. Sales volumes for the remaining six blenders ranged from one to three million Imperial gallons annually.

Interviews were conducted with five blenders serving Ontario.

Three of these blenders are subsidiaries of companies having headquarters outside of Canada. Two of the blenders are privately owned firms.

The interviews were conducted with the Presidents or Managing Officers at each of the five firms interviewed. The respondents' average (arithmetic) years of experience in the blending industry was 22 years, with a mode of 21 years. The respondents' average (arithmetic) years of service with the firm was 19.5 years, with a mode of 20 years.

6.4.5 Market Segmentation in Ontario

The firms interviewed account for preparation and marketing of 12 million Imperial gallons, or 80 percent of total estimated 1975 sales



in Ontario of finished lube oil products by the independent blenders. This represents about 12 percent of all blended oil sold in Ontario. Based on the 1975 Forecast of Lubricating Oil Sales in Ontario by Type of Oil (see Table 5.21 in Chapter 5), blenders supplied about 24 percent of the automotive oils used in Ontario and about 9 percent of the industrial oils.

In 1975 lube oil sales by all Ontario blenders amounted to 15 million Imperial gallons. Of this total, 10.5 million gallons, or 70 percent was sold for automotive use, and 4.5 million gallons or 30 percent was sold for industrial use.

6.4.6 Volumes of Base Lubricating Oils Required

Finished lube oils consist of a blend of base oils and chemical additives. Thus the raw material requirements of blenders do not consist entirely of lubricating oils. The fraction, by volume, of a finished product which is base oil can vary substantially. For example, additives account for about 20 volume percent of a high quality (API/SAE specification SE) automotive crankcase oil. The additive fraction of industrial oils can vary from less than 1 volume percent to 60 volume percent. However, hydraulic, metalworking, and gear oils, which account for a major portion of total industrial oil consumption, contain a smaller fraction of additives than automotive crankcase oils. In general, the lube oil fraction of these industrial oils is about 90 volume percent. This figure is used in the following analysis of base oil demand by blenders. Table 6.1 provides a summary for 1975 of base oil requirements of blenders in Ontario.



TABLE 6.1

Base Oil Requirements
Of The Blending Industry In
Ontario in 1975

	<u>1975 Sales of Finished Product (Millions of Imperial Gallons)</u>	<u>Percentage of Base Oils</u>	<u>Required Base Oils (Millions of Imperial Gallons)</u>
Automotive	10.5	80	8.4
Industrial Oils	<u>4.5</u>	<u>90</u>	<u>4.1</u>
Total	15.0		12.5



The potential market remains significant for a re-refiner even if a conservative evaluation of the amount of base oil is assumed. Should each of the base oil percentages in Table 6.1 be reduced by 10 percent, a market of 11 million Imperial gallons annually of base oil still remains.

6.4.7 Prices Paid for Base Lubricating Oils

During the interviews with the Ontario blenders, the topic of current prices for base oils was reviewed. The average purchase price paid by the blenders during December, 1975 and January, 1976 was 70.5 cents/Imperial gallon. Actual prices ranged from 65 to 75 cents/Imperial gallon. A large order, placed in late January, 1976, for about 2 million Imperial gallons was made at a price of 73.5 cents/Imperial gallon.

All the blenders interviewed anticipated that the price of base oil would rise sharply, and, as a tangible indication, one firm had just received an internal quotation from its U.S.A. headquarters for 87.5 cents/delivered Imperial gallon.

6.4.8 Base Lubricating Oil Specifications

Specification requirements for base oils and the quality of re-refined oils are addressed in detail within Chapter 2. This section reviews comments made by the blenders regarding desired base oil specifications.



The preparation of a high quality metalworking oil requires a naphthenic base oil having a viscosity of 100 Saybolt Universal Seconds (SUS) at 100° F.

A major portion of the automotive oils are multigrade oils. Multigrade oils (e.g. 10W-40, 5W-30) are produced by blending light neutral base oils with viscosity index improvers. According to the blenders interviewed, a 100 neutral base oil is required to produce multigrade oils for the Ontario automotive market. A 100 neutral base oil has a viscosity of 100 SUS at 100° F.

6.4.9 Attitudes and Knowledge--Re-refining and Recycling

The questions used in interviews with the blenders regarding re-refined oil were the same as those used in interviews with the industrial firms. The responses of the blenders indicate that they have considerable knowledge of re-refining and the properties of re-refined oil. In fact, one of the blenders had been in the re-refining business. Another blender was aware of recycling processes because oil recycling was being carried out at two of his firm's blending locations in the United States. Recycling, as previously described in Section 6.2, is a cleaning process only. This latter blender was now studying the development of recycling at his Ontario location.

One blender indicated he would welcome the opportunity to reduce his dependence on the major oil companies by purchasing re-refined base oil. However, such a comment is not necessarily an indication of actual purchasing attitudes. The availability of re-refined base oils could be used for leverage during negotiations with major oil companies in order to improve the terms of agreement.



Two concepts typically underscored the interviews. To be successful, a re-refiner must provide assurance of consistent quality and quantity before a blender would rely on a re-refiner for a major fraction of his base oil requirements. However, one major blender summarized his attitude toward re-refined oil by stating that if these two conditions were met and the re-refiner offered a slight price advantage, "I'd buy everything a re-refiner could produce."

6.5 Major Marketing Channels in Ontario and Summary Assessment of the Potential Market for Re-Refined Products

6.5.1 Introduction

The purpose of this section is to describe the major marketing channels for lubricating oil products in Ontario with emphasis on those channels available to a re-refiner. Estimates of the potential degree of success obtainable in those channels and the sensitivity of this success to pricing in each applicable channel are also provided.

The discussion is organized as follows:

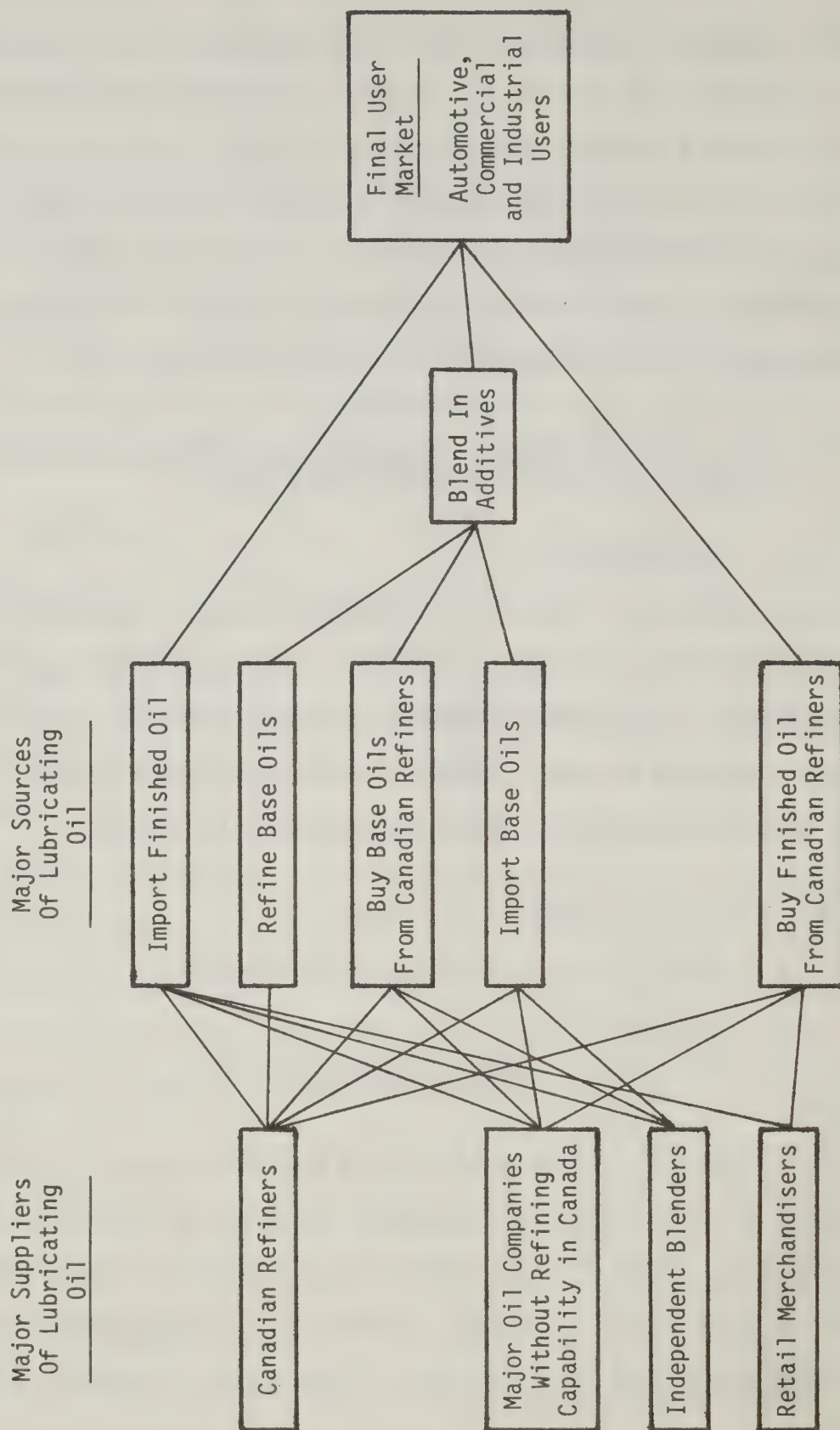
- Major Lubricating Oil Marketing Channels
- Wholesale Market
- Closed-cycle Commercial/Industrial Market

6.5.2 Major Lubricating Oil Marketing Channels

Figure 6.1 is a display of the market channels for lubricating oils in Ontario. There are four categories of suppliers of lubricating oil in the Province. The first category includes the three major oil companies who have their own lube oil refineries in Canada: Gulf,



Figure 6.1
Major Lubricating Oil Marketing Channels



Imperial and Shell. The second category includes the other major oil companies who do not have lubricating oil refining capability in Canada. The third category includes the independent blenders who do not have refining capability but do have blending capability. The last category is the retail merchandisers, who have neither refining nor blending capability, but do have ready access to the final user market.

There are three ways in which a marketer can obtain lubricating oil:

1. Refine crude oil to produce lube oil.
2. Purchase base or finished oils from one of the three Canadian refiners.
3. Import base or finished lubricating oils.

As shown in Figure 6.1, not all of these alternatives are available to each of the four categories of suppliers of lubricating oil.

Only limited quantitative data exist pertaining to each channel in Figure 6.1. Neither Statistics Canada data nor the results from the survey of major marketers provided sufficient detail. However, the limited available data are useful in defining the potential markets for the re-refining alternatives examined in this study.

6.5.3 Wholesale Market

The market most easily accessible to a large re-refinery is the wholesale base oil market. As shown in Figure 6.1, there are three categories of suppliers of lubricating oil who purchase base oils:

- Canadian refiners of lubricating oil
- Major oil companies without refining capability in Canada
- Independent blenders



Some Canadian refiners may be expected to import a part of their base oil requirements from company-owned refineries outside of Canada. Thus, barring a major lubricating oil shortage, the Canadian refiners do not represent a major market for re-refiners selling base stocks. Major oil companies without refining capability in Canada purchase base oils from Canadian refiners and import base stocks or finished oils from company-owned refineries outside of Canada. These firms, therefore, represent a potential market for a re-refiner. Although the annual quantity of purchases is substantial, this volume cannot be established from the currently available data.

Independent blenders (see Section 6.4.6) provide the most easily accessible market for re-refined base oils. The blending industry in Ontario supplies finished products to both the automotive and industrial sectors. The bulk of the finished products is multigrade automotive crankcase oil. The other major products are hydraulic, metal-working and gear oils for industrial uses.

The total market for base oils purchased by independent blenders was approximately 12.5 million Imperial gallons in 1975. The yearly quantity of finished base oil produced by the Distillation/Clay re-refinery, described in Case 3 of Chapter 2, is about 4.18 million Imperial gallons. This product volume represents about one-third of the total market requirements should all of the base oil produced be sold to independent blenders.

Interviews with independent blenders revealed that a re-refiner could sell considerable volumes of base oil to these firms provided he could



provide assurance of supply and maintenance of product quality. However, re-refined oil would probably have to be offered at a price below the price of competing virgin oils. This is because Ontario blenders have not been faced with a shortage of virgin base oils. In fact, as discussed in detail in Chapter 5, it is probable that over the next few years the lube oil market will continue to be dominated in nature by supply rather than demand, especially in view of Gulf's plans to expand its refinery capacity. The blenders interviewed expressed the opinion that a re-refiner would have to offer a price discount ranging from 10 percent to 10 cents per Imperial gallon in order to secure the required share of the market in the early years of operation.

One important reason for the independent blenders to buy from a re-refiner is to achieve a diversification of sources of supply. Some blenders depend on the major oil companies for nearly all their base oil requirements. This alternate source of base oil supply was a desirable factor according to all the independent blenders interviewed.

Sales of bulk finished products by a large re-refiner to commercial and industrial clients could only be achieved by a major marketing effort over a period of several years. A large independent re-refiner could not effectively undertake such a marketing effort until a bulk wholesale market had been established. On the other hand, major oil companies and blenders, who have already established a good reputation and marketing channels, could immediately sell quality re-refined oil to commercial, industrial and even retail clients.



6.5.4 Closed-Cycle Industrial Market

The marketing and pricing strategies for sales of re-refined oil under closed-cycle conditions to commercial and industrial clients are not as easily definable as in the wholesale market. A number of variables must be considered that are not present in wholesale marketing.

Closed-cycle re-refining provides the client with a service rather than a product. The re-refiner is not manufacturing a lubricant. Rather he is cleaning the client's dirty oil. The client receives a high degree of consistency in the finished product because it was his oil that provided the base stock. Further, it is assumed that the client would receive ongoing technical assistance in solving his lubrication problems. Finally, the client is also provided with an environmentally acceptable means for waste oil disposal.

Based on a review of data contained in Scott's Industrial Directory-Ontario, we have concluded that there are about 50 industrial firms which utilize large quantities of hydraulic, gear and metalworking oils. Waste oils of these types can be re-refined under closed-cycle conditions using the Dehydration/Clay process described in Case 14 of Chapter 2. In Ontario a classification of major users of these types of oils would include the following industrial companies:

- Steel production and rolling mills
- Automotive and truck parts manufacturing
- Agricultural equipment parts manufacturing



In a similar manner, the review indicates there may be approximately 200 intermediate users and about 800 small users of these types of oil.

For the sake of illustration, assume that the major users purchase 30 percent of the hydraulic, gear and metalworking oils and that the intermediate and small users purchase 40 and 30 percent, respectively. The purpose of this assumption is to illustrate the minimum number of sales required each year to maintain the desired capacity of operation of the Dehydration/Clay re-refinery. On the basis of these assumptions, Table 6.2 can be constructed. As shown in the table, a relatively large number of successful sales must be made to support even the smallest re-refineries considered in this study. For example, approximately 15 sales of 114,000 Imperial gallons must be made with the large users of hydraulic, gear and metalworking oils each year to support a product output of 1.8 million Imperial gallons. The number of sales in actuality will be much greater because it will probably not be possible to sell a full 114,000 gallons with each sale during the year. In a similar manner, increasingly larger numbers of sales are required to the intermediate and small users.

Based on the interviews with industrial lube oil consumers, there is reason to believe that a considerable marketing effort will be required in order to secure the number of industrial clients discussed above. The interviews indicated that the individual purchasing lubricating oil products typically had over ten years of experience in buying oil;



TABLE 6.2
ILLUSTRATIVE EXAMPLE OF ANNUAL SALES REQUIREMENT FOR
THE DEHYDRATION/CLAY PROCESS

	Number of Firms Within Each User Category	Assumed Percentage Purchased	Total Sales In Millions Of Imperial Gallons	Assumed Average Quantity of Annual Purchase By An Individual Firm in Gallons	Number of Sales Required in Each Category to Support the Dehydration/Clay Re-Refinery Described In Case 15 of Chapter 2
Major Users	50	30%	5.7	114,000	15
Intermediate Users	200	40%	7.6	38,000	50
Small Users	800	30%	5.7	7,000	250



the purchasing department typically received lubricating oil specifications and assessments of potential suppliers from engineers within the firm, not necessarily located in Canada; and the individual purchasing oil was typically two or three levels in management below corporate officers, such as vice-presidents or executive vice-presidents. In fact, none of the individuals responsible for the purchase of lubricating oil interviewed, even in the smallest of firms contacted, reported to the corporate officer level. Thus, the early marketing effort will need to be extensive. Several years may be required for a re-refiner to secure an adequate sales volume. Once the clients have been secured, the marketing effort may be greatly decreased, provided personnel are assigned the responsibility of maintaining the then existing clients. Such maintenance will be obtained through continuous technical assistance, prompt waste oil collection and delivery of quality finished products.

Prices assumed for finished oils produced by a re-refiner in Case 15 of Chapter 2 were about 5 to 10 percent below current prices for comparable virgin oils in Ontario. In addition, the same case study assumed a payment to the industrial client of 5 cents per Imperial gallon of waste oil collected. This represents a further net price reduction. Even considering the services offered and total price reduction, the investment requirements, cost of production and rate of return after tax are very attractive for this mode of operation. In fact, further price reductions are feasible should the market become extremely competitive.



Of the companies interviewed, several industrial firms felt there was no reason to pay lower prices for re-refined oil as long as consistent quality could be assured through laboratory tests. Thus, for these clients the future market prices for re-refined oils would approximate those for lubricating oils produced from virgin stocks.



7. TECHNOLOGY FOR AN OPTIMAL RE-REFINERY

7.1 Introduction

Based on evaluations of the technology, economics and environmental impacts of available re-refining technologies considered in this study, this chapter will recommend the optimal re-refining technology for Ontario based on current and projected market conditions.

This chapter is divided into the following sections:

- Matrix Comparison of Re-refining Processes
- Sensitivity Analysis of Matrix Comparison
- Environmental Rating
- Quality of Product Rating
- Product Range Rating
- Feedstock Availability and Market Assessment
- Economic Rating
- Conclusion

7.2 Matrix Comparison of Re-Refining Process

The results of the evaluations comparing each of the five re-refining processes evaluated in this study are shown in Figure 7.1.

Two types of ranking methods have been used in the comparisons --one subjective or qualitative and the other numerical. For the numerical method, a sensitivity analysis was performed. The sensitivity analysis is presented in Section 7.3.



- Subjective Ranking Method

This method utilizes written descriptions and color coded circles to provide an assessment. The written descriptions are used to explain the characteristics of a process relevant to a certain cell of the matrix. Colored circles are used to indicate the evaluation of each process relative to the criterion indicated for each column of the matrix.

- Numerical Ranking Method

This method utilizes a numerical rating system with weighting factors for each of the important criteria for comparison.

The numerical rating system assigns to each process a rating for each criterion using a scale from zero to ten, where ten is the most desirable, and zero is the least desirable.

For each of the criteria, an evaluation is made of relevant process characteristics to establish the appropriate numerical rating.


























The criteria for process evaluation presented in the matrix are summarized below:

- Environmental Rating -- Generation of by-products during the process operation based on:
 - Degree of hazard
 - Volume of waste per unit of product produced
- Quality of Product Rating -- Effectiveness in removal of contaminants and additives, as well as effect of the process on desired product qualities.
- Product Range Rating -- Ability of the process to produce selected product classifications, either neutral or bright stocks, and to provide a desired specific gravity and viscosity.
- Feedstock Availability and Market Assessment -- Ability to obtain the required quantity of waste oil feed for a specific desired operational capacity and the ability to market the product, either base oils to the wholesale market or finished oils blended with additives to final users.



Figure 7.1

MATRIX COMPARISON OF RE-REFINING PROCESSES

	ENVIRONMENTAL RATING Weighting Factor, (.20)	QUALITY OF PRODUCT RATING Weighting Factor, (.20)	PRODUCT RANGE RATING Weighting Factor, (.05)	FEED STOCK AVAILABILITY AND MARKET ASSESSMENT RATING Weighting Factor, (.15)	ECONOMICS RATING Weighting Factor, (.40)	WEIGHTED RATING FACTOR	OVERALL NUMERICAL RANKING
ACID / CLAY PROCESS	Generates large volumes of acid sludge containing lead. Sulfur oxide emissions are a potential problem.  4 (.20) .80	Sulfuric acid reacts with, dissolves or settles metal salts, asphaltics, aromatics, organic acids, polar compounds and metals to form a sludge which is settled.  8 (.20) 1.60	Generally recover lube oil neutrals and bright stocks in proportion to feed mixture. The lack of a distillation tower limits the number of cuts that would be produced.  5 (.05) .25	Waste oil fuel requirements of about 5 million Imperial gallons may not be available due to limited known supplies and competition for waste oil. Anticipated increase in competition in lube oil market due to planned additions to refining capacity in Ontario.  0 (.15) 0	Internal rate of return after tax ranged from "not profitable" to 4.4 percent based on a selling price of 70¢ and a cost of 66¢ per Imperial gallon.  0 (.40) 0	2.65	4
EXTRACTION / ACID / CLAY PROCESS	Generates less acid sludge and sulfur oxide than acid/clay due to reduced usage of sulfuric acid. Also the sludge contains relatively less lead, but this is offset by the lead content of the high ash residue.  5 (.20) 1.00	Comments pertaining to the acid/clay process, above, apply. In addition, the process provides a means to draw off residuals insoluble in propane.  9 (.20) 1.80	Comments pertaining to the acid/clay process, above, apply.  5 (.05) .25	Comments pertaining to the acid/clay process, above, apply.  0 (.15) 0	Internal rate of return after tax ranged from 2.7 to 13.2 percent based on a selling price of 70¢ and a cost of 56¢ per Imperial gallon.  5 (.40) 2.00	5.05	3
DISTILLATION / CLAY PROCESS	Process does not require sulfuric acid. Therefore the acid sludge and potential for sulfur oxide emissions are avoided. Centrifuge caustic sludge and distillation bottoms contain lead. Oily clay is also produced.  7 (.20) 1.40	During the distillation process the suspended solids and other impurities are collected in the vacuum tower bottoms and are removed. Spent additives are removed by treatment with caustic followed by centrifuging.  8 (.20) 1.60	The distillation process recovers neutrals; bright stocks become part of the high ash fuel. The distillation tower can produce several grades in continuous operation.  8 (.05) .40	Comments pertaining to the acid/clay process, above, apply.  0 (.15) 0	Internal rate of return after tax ranged from 9.7 to 23.5 percent based on a selling price of 70¢ and a cost of 49¢ per Imperial gallon.  9 (.40) 3.60	7.00	2
DISTILLATION / HYDROTREATMENT PROCESS	No clay is required. Otherwise residuals production is the same as Distillation/Clay. Elimination of clay provides a marginal advantage over the Distillation/Clay process.  8 (.20) 1.60	Comments pertaining to the distillation/clay process, above, apply. In addition, hydrotreating removes asphaltines, sulfur, and produces a clean product.  9 (.20) 1.80	Comments pertaining to the distillation/clay process, above, apply. Hydrotreating adds hydrogen to the oils, thus slightly reducing the specific gravity and viscosity.  8 (.05) .40	Comments pertaining to the acid/clay process, above, apply.  0 (.15) 0	Internal rate of return after tax ranged from 6.2 to 18.5 percent based on a selling price of 70¢ and a cost of 51¢ per Imperial gallon.  8 (.40) 3.20	7.00	2
DEHYDRATION / CLAY PROCESS (Closed contractual relationship with industrial firms.)	No lead- or caustic-containing wastes as in distillation processes. Only clay is produced.  9 (.20) 1.80	Industrial oils provide the waste feed stock and tend to contain fewer contaminants and dispersant additives. Process cannot accept crank case oils.  8 (.20) 1.60	The product grade is closely related to the batch of waste oil processed. Close control of waste oil received is required in order to produce the product desired  6 (.05) .30	Waste oil feed requirements of about 2 million Imperial gallons represent about 20 percent of known annual volume. Closed industrial contracts reduce the risk of competition from new sources of supply.  5 (.15) .75	Internal rate of return after tax of 18.5 percent based on selling a blended finished product with a cost of production of base oil of 52¢ per Imperial gallon.  8 (.40) 3.20	7.65	1

Rating Factor x (Weighting Factor) = **Weighted Rating Factor**

 MOST DESIRABLE
  FAVORABLE
  ACCEPTABLE
  ADEQUATE
  MARGINAL

- Economic Rating -- Assessment of economic desirability based on the amount of initial capital investment required, unit cost to produce a gallon of product, and estimated percentage rate of return after tax.

To account for the relative importance of each of the above criteria, the following weighting factors were utilized in the base case evaluation:

- Economic Weighting Factor .40
 - Environmental Weighting Factor .20
 - Other Factors
 - Quality Weighting Factor .20
 - Product Range Weighting Factor .05
 - Feedstock Availability and Market Assessment .15
- .40
1.00

During the evaluation, the numerical rating given to each criterion for each re-refining process is multiplied by the appropriate weighting factor. The overall re-refining process rating factor is obtained by totaling ratings for the various criteria. The re-refining process with the highest total is the most desirable.

7.3 Sensitivity Analysis of Matrix Comparison

Sensitivity analysis was performed using the numerical rating system described above and the alternative cases presented in Table 7.1. Comparisons of the overall ranking of the re-refining technologies for the cases listed in Table 7.1 are presented in Table 7.2.

This method of sensitivity analysis enables the consideration of different viewpoints. Using this approach, the following



Table 7.1
Sensitivity Analysis
of the
Numerical Ratings in the Matrix

Base Case

1. Economic Weighting Factor	.40
2. Environmental Weighting Factor	.20
3. Other Factors Combined	
a. Quality Weighting Factor	.20
b. Product Range Weighting Factor	.05
c. Feedstock Availability and Market Assessment Weighting Factor	.15
	<u>.40</u>

Combined Weighting Factor 1.00

Case 1

1. Economic Factor remains	.40
2. Environmental Factor increases to	.30
3. Quality Factor decreases to	.10
4. Product Range Factor remains	.05
5. Feedstock Availability and Market Assessment Factor remains	.15
	<u>1.00</u>

Case 2

1. Economic Factor decreased to	.30
2. Environmental Factor increased to	.30
3. Other Factors remain the same	.40
	<u>1.00</u>

Case 3

1. Economic Factor decreases to	.20
2. Environmental Factor increases to	.40
3. Other Factors remain the same	.40
	<u>1.00</u>

Case 4

1. Economic Factor increased to	.50
2. Environmental Factor remains	.20
3. Quality Factor decreases to	.10
4. Other Factors remain	.20
	<u>1.00</u>



Table 7.2

Overall Ranking of Re-refining Process Using
Different Weighting Factors for Relevant Criteria*

	<u>Base Case</u>	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>	<u>Case 4</u>
Dehydration/Clay	1	1	1	1	1
Distillation/Clay	2	2	3	3	2
Distillation/Hydrotreating	2	2	2	2	3
Extraction/Acid/Clay	3	3	4	4	4
Acid/Clay	4	4	5	5	5

* Processes are ranked on a scale of 1 to 5, where 1 is the most preferable and 5 is the least preferable.



conclusions can be reached:

- Within a reasonable range of ratings, certain technologies appear as either most acceptable (thus focusing attention on those technologies) or most unacceptable (thus eliminating them from consideration).
- If the ranking of one or more technologies changes dramatically as weights are varied, the critical factor causing the change can be isolated for further analysis.
- The use of sensitivity analysis, properly explained, along with the subjective ranking system described above, is an effective method of focusing attention of public bodies and interest groups upon the critical issues.

Cases 1 through 3 in Table 7.1 represent the alternatives for increasing the dominance of the "Environmental Rating" weighting factor, and the simultaneous reduction of importance of the "Economic Rating." Case 4 represents an assessment of increasing the Economic Rating above the original level assumed in the base case.

The base case ranking indicates that the Dehydration/Clay process is the most desirable. Its weighted rating factor of 7.65 is notably above that of either the Distillation/Clay (7.00) or the Distillation/Hydrotreating (also 7.00) process. Both the processes utilizing acid treatment have weighted rating factors sufficiently low to be considered unacceptable in relation to the other re-refining technologies.

The Dehydration/Clay process remained the most desirable in all of the alternative cases used in the sensitivity analysis. In a similar manner, both acid treatment processes maintained their respective low



rankings. Within the sensitivity analysis only the distillation processes reversed their respective positions. However, considering the qualitative nature of this type of evaluation, both distillation processes should be considered equally desirable.

The relative rating factors for each evaluation criterion were based on the analysis performed in this study. The rationale for each rating is presented within the text of the matrix. Further detailed description pertaining to the rationale for selecting specific ratings is presented in the following sections of this chapter.

7.4 Environmental Rating

The environmental evaluation of the alternative re-refining technologies has been provided in Chapter 3 of this study. The resultant environmental ratings are presented within the matrix in Figure 7.1. The degree of the hazard and the volume of waste per unit of product are the key determinants in the environmental assessment.

The most environmentally desirable technology is the Dehydration/Clay process. This process produces a waste that may be classified as a "nuisance," rather than a hazard. The re-refining technologies were compared to this reference point.

The Distillation/Hydrotreating process requires no clay, whereas the Distillation/Clay process does. Therefore, the hydrotreating process has a higher rating. However, the relative differential is small because oily clay is not considered to be hazardous; rather it is more



of a volumetric nuisance. Both of these processes are rated lower than the Dehydration/Clay process because they do produce wastes containing lead and caustic. Since only industrial oils can be re-refined using the Dehydration/Clay process, no lead containing wastes are produced.

The Extraction/Acid/Clay process is rated higher than the Acid/Clay process because smaller quantities of lead and acid bearing sludge are produced. Both acid treatment processes have lower ratings than the distillation processes due to the acid content in the waste.

7.5 Quality of Product Rating

The quality of re-refined oil is addressed in the technical descriptions of each process described in Chapter 1. Evaluations of laboratory samples from three of the technologies are provided within the latter half of Chapter 2. The quality ratings are presented within the matrix in Figure 7.1.

All the processes considered in this study provide the capability to produce high quality products. There are only minor differences in the quality of oils produced using the different technologies.

The Extraction/Acid/Clay process is rated higher than the Acid/Clay process because the extraction operation provides a means to draw off residuals insoluble in propane. Both processes utilize sulfuric acid that reacts with, dissolves or settles metal salts, asphaltics, aromatics, organic acids, polar compounds, metals and dirt to form a sludge. This sludge settles out of the solution and is drawn off.



The Distillation/Hydrotreating process is rated higher than the Distillation/Clay process because hydrotreating is extremely effective in removing sulfur and color bodies thereby producing an extremely clear product. Both processes use the distillation technique in which suspended solids and other impurities are collected in the vacuum tower for removal. Spent additives are removed by treatment with caustic followed by centrifuging.

The ability of the Dehydration/Clay process to produce a high quality product is highly dependent on control of the waste oil received. The feedstock must consist of industrial oils, separated by type of product. Each type of waste industrial oil is re-refined in a separate batch operation. Most industrial waste oil contains significantly fewer contaminants and dispersant additives than used crankcase oils. Hence, fewer undesirable wastes are produced.

7.6 Product Range Rating

The evaluation of the product range potential for each re-refining technology is presented in Chapter 1.

The basis for the ratings presented in the matrix in Figure 7.1 is the ability of each process to produce selected product classifications. Such classifications include the ability to produce neutral or bright stocks having a range of specific gravities and viscosities.

Both acid treatment processes are rated the lowest, relative to the other technologies, because they generally recover a blend of lube oils containing neutrals and bright stocks in proportion to the composition



of the waste oil feed. The neutrals and bright stocks could be separated in a vacuum distillation; however, this would require a significant increase in cost. The intended major market for the re-refined base stock from the relatively high volume designs considered in this study is the Ontario wholesale market. Based on interviews with purchasers in the wholesale market, neutral oils are the predominantly desired base stock. This is especially important where multi-grade oil is the finished product. Such a market situation exists in Ontario where, because of severe winter weather, lower viscosity oils are required. This is not the case in warmer climates. Bright stocks are normally used to produce a heavier grade oil needed at elevated temperatures.

The foregoing comments are not meant to indicate the lack of a wholesale market for bright stocks in Ontario. However, the results of the interviews described in Chapter 6 indicate that most of the independent blenders purchasing base oil on the wholesale market require light neutral oils for producing multi-grade finished oils.

The utilization of a vacuum distillation tower allows the separation of the neutral and bright stocks. The neutrals are recovered from the process and the bright stocks become part of the high ash fuel which is drawn off for use or sale. The distillation tower also provides the ability to produce selected specific gravities and viscosities, in a continuous operation.

The hydrotreating process adds hydrogen to the finished base oil. This tends to produce an oil having a slightly lower specific gravity



than the product produced from the Distillation/Clay process. The effect on product range is, however, minor.

Since waste industrial oils are separated by type and processed in separate batch operations, the Dehydration/Clay process provides the final user of a specific finished oil with his exact requirements. Therefore, the rating assigned in the matrix could be higher than shown. The reason the lower rating was selected is attributable to the inability of the Dehydration/Clay process to yield products having a range of viscosities. This represents a lack of flexibility in comparison to the distillation processes. Thus, the Dehydration/Clay process is rated below the distillation processes.

7.7 Feedstock Availability and Market Assessment

Process ratings under these criteria are based on:

- The ability to obtain the required quantity of waste oil feed for a given operational capacity.
- The ability to market the product.

The major market for products from both the acid treatment processes and both the distillation processes consists of lube oil blenders. The market for products from the Dehydration/Clay process consists of industrial clients with whom contractual arrangements have been established.

The waste oil feed requirement for the larger re-refining processes evaluated in this study is about 5 million Imperial gallons a year. This represents more than half of the known quantity of waste oil collected in Ontario each year.



There are two alternative markets for waste oil that would provide competition to a re-refiner seeking to secure adequate volumes of feed-stock. The first market is municipalities which use waste oil as a dust suppressant on rural roads. These municipalities typically contract with road oiling firms, who are for the most part also waste oil collectors, to have the roads sprayed. The other major market currently existing in Ontario is the burning of waste oil as a fuel in cement manufacturing.

Two additional markets for the use of waste oil should be considered. One is the use of industrial waste oil as a fuel within the industry of origin; the second market is the collection and sale of waste oil as a fuel either within Canada or in bordering areas of the U.S.

The uncertainty in the availability of waste oil in Ontario is graphically depicted in Figure 2.3 in Chapter 2 entitled "Simplified Flow Sheet for the Lubricating Oil Cycle in Ontario."

In summary, over 87 million Imperial gallons of lubricating oil are currently being purchased annually in Ontario. Approximately 9-10 million Imperial gallons of waste oil have been accounted for in recent preliminary surveys. Some waste oil is, of course, consumed in service, but according to estimates by Environment Canada, in Ontario 22 million gallons of used oil cannot be accounted for.

Based on the uncertainty of waste oil supply in Ontario, the larger re-refineries evaluated in this study received a zero rating for this



evaluation criterion. This rating has a substantial effect on the total weighted rating factor and the recommendations of this report.

The Dehydration/Clay process requires about 2 million gallons of waste oil feedstock annually. The industrial waste oil required is collected under contractual conditions by the re-refiner; the capital and operating costs for such collection have been included within the evaluation. The Dehydration/Clay re-refiner considered in this study is, therefore, somewhat insulated from competition provided by other markets for limited supplies of waste oil.

The ability to market the re-refined product is the second evaluation criterion.

In 1969, Shell opened a major refinery in Quebec which produces a wide range of petroleum products including lubricating oils. An analysis of the impact of the Shell refinery on the lube oil market in Ontario, Quebec and Canada has been provided in Chapter 5. The opening of the Shell refinery extensively disrupted the previously existing market balance.

The Gulf refinery, with more than twice the lube capacity of the Shell refinery, is currently planned to be opened in 1979 in Ontario. Thus, based on historical precedent, several generalizations may be made to estimate the effect on the lube oil market. The demand for imports will fall sharply. At the outset, Gulf will not be able to market all of its lube oil production directly to final users. As the level of demand increases, Gulf's final user market will also grow.



During this period, Gulf may be expected to increase its sales in the Canadian wholesale market. This focus on the wholesale market will provide competition for other suppliers of base oils, including a large waste oil re-refiner. Further details of this situation are provided in Section 5.8.

In contrast, the Dehydration/Clay re-refiner would be somewhat insulated from the increased competition in the lube oil market. This insulation would be provided by contractual arrangements to provide a full range of services, such as the collection of the industries' waste oil and the provision of finished products (blended with additives) to meet specific needs. Further, the economic analysis provided in Chapter 2 indicates that the Distillation/Clay re-refiner selling finished oils is in a stronger competitive position than re-refiners producing base oils for the wholesale market.

7.8 Economic Rating

The economic analysis of re-refining processes is presented in detail within the first half of Chapter 2.

The economic ratings provided in the matrix in Figure 7.1 are based on the following criteria:

- The amount of initial capital investment.
- Unit cost to produce a gallon of base oil.
- Estimated percentage rate of return after tax.

Data for each of these criteria are presented in Table 7.3.



Table 7.3

Economic Rating
Evaluation Criteria

	Initial Capital Invest- ment (\$1,000)	Annual Production (1,000 Imperial Gallons)	Average Cost to Produce an Imperial Gallon (¢/IG)	Percentage Rate of Return after Tax at a 71¢/ Imperial Gallon Price for the Base Stock
Acid/Clay Process	\$3,229	3,960	66¢	4.4%
Extraction/Acid/Clay Process	\$4,419	4,579	56¢	13.2%
Distillation/Clay Process	\$2,970	4,180	49¢	23.5%
Distillation/Hydrotreating Process	\$3,636	4,180	51¢	18.5%
Dehydration/Clay Process	\$1,910	1,800	52¢	18.5%*

* Rate of return after tax based on a net increase in profits of 6¢ per gallon attributable to blending of additives with re-refined industrial oils. Without such blending the net rate of return is 14.4%.



Based on the economic evaluations of each re-refining technology, the Distillation/Clay process provides the most attractive investment alternative. The Distillation/Hydrotreating and Dehydration/Clay processes are ranked second. The Dehydration/Clay process might prove slightly more attractive due to the smaller capital investment requirement.

Economic evaluations normally include a minimum level "rate of return on investment" requirement. Current investors might typically require at least an 8 to 12 percent rate of return for the risks involved in the re-refining industry. Based on these levels, the Extraction/Acid/Clay process is only marginally attractive; the Acid/Clay process is not an attractive investment. In fact, an investment in a bank savings account would prove to be more attractive, at less risk, than an investment in the Acid/Clay process.

7.9 Conclusion

The recommended optimal technology for a re-refinery in Ontario based on current and projected conditions is the Dehydration/Clay process operated on a "closed-cycle" contractual basis with industrial clients. Such a recommendation is dependent on a specific "potential adverse condition." This condition is the uncertain availability of waste oil feedstock in sufficient quantities to operate a relatively large re-refinery at the required level of capacity.

Should the feedstock availability and market assessment rating for the four large re-refining technologies be raised to five or more, the Distillation/Clay and Distillation/Hydrotreating processes would be the two most



attractive alternatives. Such a rating might be applicable if there were a greater assurance of supply, either through location of additional sources of waste oil or through the provision of guaranteed allocations from currently known available supplies. However, even if an adequate supply of feedstock could be assured, increased competition in the wholesale market due to large scale expansion of lube producing capacity in Ontario may pose a threat to profitability of a large scale re-refinery.



